Achieving Greater Impact from Research Investments in Africa

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Sasakawa Africa Association, c/o CIMMYT, Apdo 6-641, 06600 Mexico D.F. Mexico

Global 2000, The Carter Center, One Copenhill Road, Atlanta, GA 30307, USA

CASIN, 69, rue de Lausanne, 1202 Geneva, Switzerland

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Abstract: This publication is the eighth in a series of workshops that explore measures for improving sub-Saharan Africa's food security and other issues relevant to economic progress in the region. The chapters cover agricultural modernization strategies in Ethiopia, the process of agricultural and technology generation, case histories of successful technology diffusion in sub-Saharan Africa, trends in investment in research and extension in the region, gender issues in technology generation and transfer, and infrastructure, inputs, and market systems in relation to technology diffusion.

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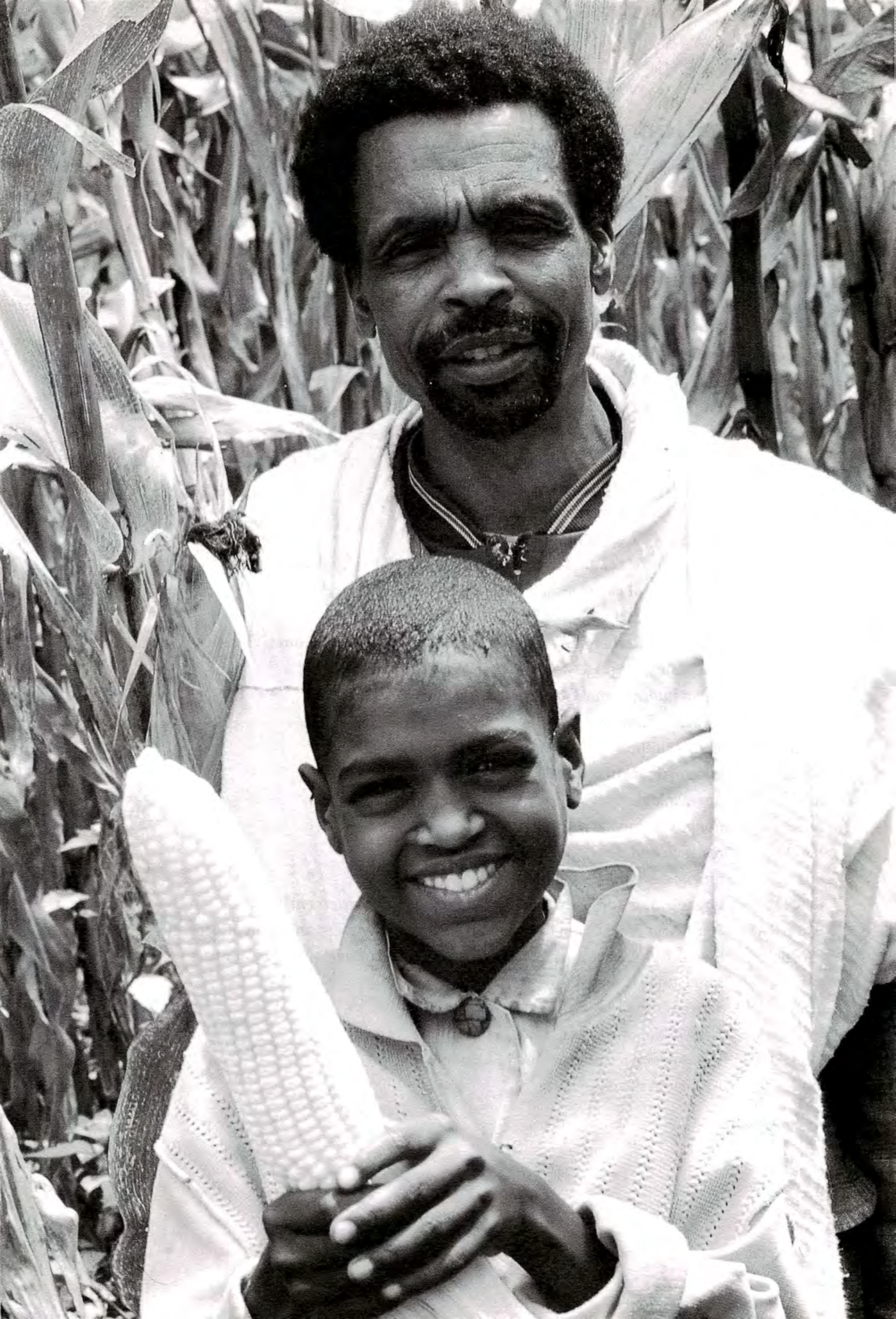
Abbreviations

AgGDP	agricultural gross domestic product
¢	cedi (Ghana)
CFA	franc de la Coopération Finacière en Afrique
c.i.f.	cost, insurance, freight
CIMMYT	International Maize and Wheat Improvement Center
EB	Ethiopian birr
ECA	UN Economic Commission for Africa
EU	European Union
EMBRAPA	Empresa Brasileira de Pesquisa Agropecuária
FAO	Food and Agriculture Organization
f.o.b.	free on board
GDP	gross domestic product
GEF	Global Environmental Facility
IAR	Institute of Agricultural Research, Ethiopia
ICARDA	International Center for Agricultural Research in Dry Areas
IDRC	International Development Research Centre
IITA	International Institute of Tropical Agriculture
IRAT	Institut de Recherches Agronomiques Tropical et des Cultures Vivrières
ISNAR	International Service for National Agricultural Research
JICA	Japan International Cooperation Agency
K	kwacha (Zambia)
K Sh	Kenya shilling
MRR	marginal rate of return
na	not available
NGO	nongovernmental organization
R&D	research and development
ODA	official development assistance
OECD	Organization for Economic Cooperation and Development
SAFGRAD	Semi-Arid Food Grain Research and Development, Organisation of African Unity
SAREC	Swedish Agency for Research Cooperation with Development Countries
t	tonne (metric ton)
T Sh	Tanzania shilling
UNDP	United Nations Development Programme
USAID	U.S. Agency for International Development
WID	women in development



Africa's Agricultural Development Imperatives

Meles Zenawi

I am very pleased to welcome you all to Addis Ababa to participate in this important workshop on developing African agriculture. Its major focus, I understand, will be issues relating to ways and means of achieving greater impact from research investment.

Let me take this opportunity to pay tribute to the memory of the late Ryoichi Sasakawa, a good friend of Africa, who, during his lifetime, did so much to help the African small farmer.

I wish to express my deep appreciation and admiration for the effective and productive work that Sasakawa-Global 2000 has been doing to help increase food production in Ethiopia and in a number of other African countries south of the Sahara.

It is my hope that the deliberations at this workshop will contribute to finding new and better technological inputs so that we and others in similar situations can bring about meaningful transformation in our agricultural sectors. It is my conviction that there is a great need for directing research toward achieving better technological inputs and to diffuse the results to change the farming habits of the small-scale farmer. The two activities—research directed at developing new technological inputs and the diffusion of the results—should go hand-in-hand, it seems to me, so that the results of research have the desired impact on the lives of farmers. In our country, we taken this approach, and this principle is a major focus of the activities of relevant institutions.

In our opinion and that of many others, the projects in agriculture with which SG 2000 has been associated have been the most successful of all such projects undertaken in Africa by nongovernmental organizations.

In Ethiopia, the high estimation and appreciation we have for the program and for SG 2000 is reflected in our decision to accept the program and in the effort we have been making to ensure its full implementation.

Frankly the SG 2000 program possesses quite a few attributes that are unique and that put it in a special category compared with other programs that also aim to bring about positive changes in agricultural production in Africa and other developing countries.

It is to be noted that a number of governmental and nongovernmental organizations active in Africa, in the agricultural sector or in other sectors and areas, have found it difficult to resist the temptation to set up their own bureaucracies alongside existing government institutions, thereby inadvertently creating obstacles to the successful implementation of programs. Of no less of concern has been the amount of resources—by no means a negligible portion of the total assistance secured—that goes for covering administrative costs.

On the other hand, in sharp contrast to the aforementioned method of making aid available, SG 2000 has followed the welcome principle of working within government

Meles Zenawi is the Prime Minister of Ethiopia.

institutions, eschewing practices resorted to by others in connection with the creation of their own bureaucracies. The practice chosen by SG 2000 of assigning only one representative to work in close collaboration with focal institutions or ministries has meant that every cent that comes through the program is used directly for the purpose of improving the life of the farmer, with no money being unnecessarily spent for administrative purposes. That is a major plus for SG 2000.

The technological package prepared, as in the case of Ethiopia, is mainly of local origin. The extension agents used are the same ones employed by the government. The peasants are supposed to graduate in the sense of being able to fend for themselves, without the revolving fund of SG 2000, in 2 to 3 years. These and many other such characteristics make the SG 2000 program replicable and sustainable. One living proof of that is the fact that we, in the government, have begun a pilot project to include some 30,000 to 40,000 farming families.

The SG 2000 program possesses a number of other advantages that taken together make it very easily sustainable as well as replicable—facts that are especially pertinent to societies such as ours where there is a critical need for a speedy transformation of the agricultural sector. Among them are its credit policy, which is based on a revolving fund system, and its reliance on inputs that are locally produced.

It is obvious that what SG 2000 has been doing, here in Ethiopia and in other parts of Africa is exemplary, and it is the type of approach to assistance that needs to be followed and emulated by others.

The results we have had so far from the SG 2000 program are rather encouraging. Reference should be made in this context to our own pilot project whose implementation is well under way and in which 30,000 to 40,000 farmers are participating. The areas that have been chosen for the implementation of this project are known for having satisfactory rainfall. We intend to expand this program next year, following an evaluation of the results, with the aim of involving 5 to 10 times as many farmers as are involved in the program at present. We also intend to replicate the results achieved in other areas, including areas that get little rainfall, with the view to making the new system also applicable to drought-affected areas.

The role that SG 2000 has started to play in Ethiopia is deeply appreciated, and it is our hope that the program will further enhance its activities in our country and will continue to be our partner in the major effort we have embarked upon to ensure food self-sufficiency for our people. It is also my hope that other governmental and nongovernmental organizations would closely study the approach utilized by SG 2000 so that it may be possible for them to follow in its footsteps in the provision of inputs to improve our agricultural activities and activities and production in other sectors as well.

Finally, I wish to express my conviction that with redoubled efforts on the part of our people and with the active cooperation of our partners, like SG 2000, we will be able to avert the kind of devastation that hit our country 10 years ago—a tragic calamity that destroyed the lives of millions of our people as well as decimated our livestock.

In concluding, I would like to pay tribute to all those who are associated with SG 2000 for the very good job they are doing, and I wish to assure them that their contribution is very much appreciated here in Ethiopia as, I am sure, it is in other parts of Africa as well.

Opening Statement

Jimmy Carter

Just a few days ago, I was in Tokyo to participate in a ceremony to commemorate the memory of and to pay homage to Ryoichi Sasakawa with whom we met a long road and a decade ago to address this serious problem of starvation in Africa. It would take all morning for me to outline the things I can remember about this wonderful gentleman. One of the most vivid images I have is Mr. Sasakawa at the age of 86 running across the fields with a small African child on his shoulders. To me this is symbolic of what Mr. Sasakawa wanted to do: to let the poor, the deprived, the starving, the homeless, the orphans ride on his shoulders. My wife and I have been to many places in the world to see the good work that Mr. Sasakawa did. I mentioned at the funeral ceremony two places in Thailand where we visited several hundred boys and girls in separate schools who were receiving food, clothing, and an education, self respect, security, care—all of whose parents were isolated because they had leprosy. To me this is typical of what Mr. Sasakawa and his great foundation did in many places around the world.

I think I should also mention our co-chairman who is not here. A long-time friend of mine, he was president of Nigeria when I was president of the United States. President Obasanjo, as you know has been involved with SG 2000 since its early stages. He is under detention now by a military dictatorship that has alleged that he was part of a conspiracy to overthrow the government. My wife and I have been to Abuja, in Nigeria, seeking his release, and the first time we were there, when he was in isolation, he was permitted because of our entreaties to go back to his farm, but 2 or 3 weeks later he was arrested again and he is still in detention. The day before I left my home, just a few days ago, I talked to General Abacha, the present leader of Nigeria, urging again that this man, one of the great leaders of Africa be released. I think we should all remember him in our prayers and use our political and other influence to ensure the release of President Obasanjo.

This morning, we will be hearing a lot of statistics, a lot information, accurate data, reports on the progress and achievements of Sasakawa-Global 2000 in Africa, and I always look forward to those meetings. There is no subterfuge in these reports. Sometimes we have disappointments, sometimes we have glorious success and, again, we will receive a good report. It is these annual assessments that permit us to continue our upward progress. I think that the statistics are inspiring in themselves, but the personal impacts on families in many cultures in Africa is what impresses me most.

I remember visiting a small farm near the base of Mount Kilimanjaro, where a very proud farmer was sitting on a large stack of maize. I asked him how much he had made on his small plot. He said 26 bags. I asked how much he had ever made before. He replied that the maximum was five bags. I asked him if this had an impact on his family. He said, yes. His sons were married, and they had to move to Dar-es-Salaam to try to

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Jimmy Carter is the former President of the United States.

get a job, living in the suburbs and ghettos of the capital city. But now, with SG 2000, his sons were coming back home because the whole family could survive on these high yields. Not long ago, my wife and I went to Benin and we saw a whole community come together, dominated apparently, to my concern, by women. The farmers were bringing in their maize and bags. The women were in charge of carefully weighing the bags, which were put in common storage. The women took care of keeping books and how much each farm family possessed. This was the third year after the SG 2000 program, and they had made a total of US$6,000 in profits in that community. They have bought a few oxen and renovated and built new homes for every family, a totally different, vibrant community of hope, of confidence, of self-respect, of achievement. Their dreams for the future, I feel certain, will be realized.

The last incident I want to mention was in Ethiopia. The last time I was here visiting with Marco Quiñones, I had a meeting with President Meles Zenawi of the then transitional government. I asked if he would go with us to the plots, and he did. And when he saw the difference between what had been done on this terrible vertisol farm and what was currently being done by Sasakawa-Global 2000, he left me and Dr. Quiñones and went by himself to the farm families and had a heated and impassioned discussion, which I could not understand. And on the way home he said, "I want you and Dr. Quiñones to give me the most ambitious Sasakawa-Global 2000 projections of rapid progress and expansion you can possibly imagine." I told that to Dr. Quiñones and he stayed up all night. The next morning he brought to me what I thought a fairly aggressive program. It was far too modest for Meles Zenawi, and eventually Dr. Quiñones had to go back two or three times and instead of having a few hundred test plots, there are now over 30,000. In addition to the regular plots of SG 2000, I think that this will transform Ethiopia's agriculture and put into production vast areas of heavy clay soil that was formerly hardly productive at all.

I am deeply grateful for having been part of this wonderful project, to work side by side with Norman Borlaug, under the general direction of Ryoichi Sasakawa, his son Yohei and his associates from Japan.

Thank you all for letting me be part of this wonderful experiment, which I am sure will bring much greater quality of life to the people of Africa.

Introductory Comments

Yohei Sasakawa

It is a great honor and, at the same time, an immense pleasure to participate in this workshop the eighth in its series. I am saddened that our co-chairman, General Olusegun Obasanjo is unable to join us on this occasion.

First of all, I would like to sincerely thank each of you who extended your warm condolences to my family at the passing away of my father Ryoichi Sasakawa. Among his departing words were ones of gratitude to people such as yourselves who have made his life happy and fulfilled. He died at the age of 96, though he believed he could live and continue to serve beyond 100. We, who were close to him, will continue to feel and be inspired by his indomitable spirit. I am personally determined and dedicated to continuing and expanding the assistance activities of the Nippon Foundation, which my father founded some 33 years ago.

It has now been 10 years since we held the first workshop in Geneva on this subject of African agricultural development. That ground-breaking workshop was attended by Dr. Borlaug, President Carter, my father, and myself, among others. Out of it was launched the agricultural initiative we call SG 2000, which places emphasis on field demonstration and extension of modern food crop technologies. Subsequently, this initiative has been cultivated into a full-fledged program, and SG 2000 has gained recognition as being one of the most dynamic nongovernmental organizations engaged in agricultural development in the African arena.

Thanks to the efforts of the hard-working staff of Sasakawa-Global 2000 and of our national counterpart organizations, and to the immense contributions of Dr. Borlaug and President Carter, the SG 2000 program is now yielding fruitful results. We are attracting considerable attention from other organizations, though I am afraid our reputation sometimes casts a larger shadow than our actual program.

We are, in fact, a relatively small NGO, with considerably less financial and human resources than required to meet the tasks ahead of us. We must, therefore, call on other international development organizations to join with us as partners in this vital work to assist the nations of Africa. To our great joy, we were able last year to form such a partnership with the World Bank. This collaboration in fields of mutual interests helps to maximize the investments of all concerned, including the national governments. We hope to develop more collaborations like this with other bilateral and multilateral donors as well as with other NGOs.

I believe that the most important duty of any political leader is to achieve the well-being of his people. The first step in doing so is to ensure that they are guaranteed "food security." If an adequate food supply is ensured, half of the country's problems

Yohei Sasakawa is President, The Nippon Foundation, Tokyo, Japan.

will be solved. I am aware that African leaders are, at the moment, faced with a very difficult situation due to structural adjustments implemented in their public sectors and economies. Serious consideration should also be given to installing debt-relief programs as well. However, this critical juncture in African history demands that the continent's leaders place a high priority on agricultural development. I am encouraged to see positive signs in this direction of late. More and more African leaders are focusing their attention on agriculture and are investing greater resources in rural development. I am pleased that we could have played a role in bringing about this enhanced awareness.

I know that some criticisms have been levied against us, the biggest being that small-scale farmers are unable to afford modern technology, especially chemical fertilizer and improved seed varieties. Nevertheless, I firmly believe in Dr. Borlaug's approach, and in our ability to make it work in Africa. There can be no solution to food production shortages if we do not make effective use of the modern technologies at our disposal. Others doubt the sustainability of the activities we support. From the start, however, SG 2000 has been working in alliance with the national extension systems of our partner countries to ensure that our joint programs are implemented in a sustainable manner through these systems.

In fact, we have gradually reduced our expatriate staff to just one director, supported by a handful of locally hired technicians and office personnel. We plan to continue providing financial and technical support even after we withdraw the last member of our expatriate staff. We seek, in the same way as does the World Bank, to maintain a long-term relationship with our national partners.

The main theme of our workshop this year is how to achieve maximum impact from investments in agricultural research. This is a very timely issue. In the past, the linkages between research and extension have not been satisfactory. The result has been many good research findings left unused, or as Dr. Borlaug says, "left lying on the shelf inside of research stations." From the beginning, we have been aware of the importance of research, which is vital to developing the continuing stream of improved technologies needed to support the modernization of African agriculture. At the same time, we found that even higher priority needs to be given to strengthening extension systems since many proven and readily available technologies are not being utilized. Research unused is of little value.

I would like to take a moment to comment on the responsibility of the researchers in this endeavor. I would urge you to focus your energies and talents on solving the most pressing of the on-the-ground problems faced by the farmers, rather than pursuing academic recognition. The clients served by scientific advances made through this research program should first and foremost be the small-scale, resource-poor farmers. They deserve our full dedication. I look forward to our discussions, which I am sure will be lively, producing an effective action plan to increase the impact of investments being made in agricultural research and extension.

I again promise to do my utmost to ensure that the Nippon Foundation will continue to finance the SG 2000 program. I believe it will not be that far in the future before we see African nations achieving their own green revolutions. I am both happy and proud that we can contribute to the achievement of this most noble goal.

Welcoming Address

Kingsley Y. Amoako

I would like to take this opportunity to express my sincere gratitude to the Centre for Applied Studies in International Negotiations for inviting me to address you and for selecting the Economic Commission for Africa as the venue for this workshop. Let us hope that this workshop will serve as a media reference point for assessing the quantity and culture of research investments in sustainable agricultural development.

The presence of the Prime Minister of the Federal Democratic Republic of Ethiopia, Meles Zenawi, among others, is an honor for us at ECA. It underpins the support that he has so generously extended to us since his first days as President of the Transitional Government of Ethiopia. What is more important, his presence here today is eloquent testimony to the importance that his country attaches to our agriculture-led development strategy. I would also like to pay tribute to the three distinguished personalities behind the SG 2000 agricultural projects for their unflinching support for peace, food security, and sustainable development on our continent.

Africa today is severely threatened by intractable food crises. For nearly three decades, per capita food production has failed to keep up with increases in population growth. Obviously, something has to happen. The easier ways of increasing food production are running out of steam. The only salvation is increasing science-based agricultural system and the shift from resource-based to a more science-based system with agricultural research as the key impetus.

A maize-based green revolution is slowly emerging in countries such as Zimbabwe, Malawi, Zambia, Kenya, Nigeria, Ghana, and Burkina Faso. In Zimbabwe, for instance, virtually 100 percent of the area under maize has been planted with hybrids. In Zambia, it is 60 percent and in Malawi, 24 percent. The Sasakawa-Global 2000 project, which became operational in Tanzania in 1989, has been equally successful. A few years later, project participants reported satisfactory average maize yields on their own holdings in the Arusha region. The success of the SG 2000 project was primarily attributable to a successful program of extension training. SG 2000 has also been actively involved in a range of input supplies and credit-related schemes to supply national technology programs in Benin, Ethiopia, Ghana, Mozambique, Nigeria, and Togo. But perhaps, the most encouraging harbinger of a potential green revolution in Africa is the continuous spread of improved cassava varieties from the International Institute of Tropical Agriculture located in Ibadan, Nigeria. From 1986 to 1991, IITA has made measurable progress in identifying cassava germplasm suitable for making flour. IITA's international scientists have made some significant contribution to Africa's research endeavors, but these are extraordinary.

Kingsley Y. Amoako is Executive Secretary, United Nations Economic Commission for Africa, Addis Ababa, Ethiopia.

The truth of the matter is that the situation with research investments in Africa is worrisome. First, research expenditures in many African countries are less than 1 percent of the agricultural GDP. The bulk of these expenditures is externally funded with salaries of research staff accounting for a predominant share. Second, poor government policies, dilapidated rural infrastructure, nonexistent or underdeveloped markets, and the lack of appropriate technology are formidable impediments. Third, the uncoordinated role played by too many actors—governments, donors, U.N. agencies, research centers, etc.—in the formulation and in the key issues of research programs as well as witnesses in the management of these programs have resulted in needless duplication of efforts and in the inefficient utilization of research capital.

There are possible solutions. Farmers should have a say in the organization and operation of extension services. The aspirations of local methodologists and comments should find a place in the context of extension agency programs. The farmers who are in fact the beneficiaries should define the project services that they need. Over time they should show more responsibilities toward the operation of the services including financial responsibility, but if we are to devise extension services that are relevant and effective we must ensure the participation of women farmers. In 1995 women accounted for 70 to 80 percent of household food production in sub-Saharan Africa, compared with 65 percent in Asia and 45 percent in Latin America.

Governments will have to increase their support for agricultural research and extension institutions. International donors will have to adopt a more holistic approach to striking a balance between development of trained personnel and the provision of services. Another prerequisite for success is to sharpen the focus of research through better planning and prior authorization. Hand in hand with government support, a strategic policy and planning capability, a critical mass of skilled researchers and effective monitoring and evaluation procedures are also vital ingredients for success.

In 1991–92, the Economic Commission for Africa, evaluated Africa's experience in rural development. Twenty-two African countries were the subject of this evaluation exercise. It unveiled many key conclusions including the need to focus on direct measures that increase agricultural production through participatory approaches with African farmers.

The Ethiopian program "Sustainable Agricultural and Environmental Rehabilitation" is one of several of this kind. We hope to replicate this program in other regions in Africa, initially in the Horn of Africa but gradually moving to the food-deficit areas of the Sahel. In our ongoing review of our program, we at ECA will give priority to agricultural capacity burden, including research aspects, policy analysis, and advice to enable Africa to attain the goal of food security.


EXTENSION DEMON
STRATION FARMERS
FIELD
CROP TYPE
VARIETY
SOWING DATE
SEED RATE
FERTILIZER RATE

Ethiopia's Agricultural Development Strategy

Teketel Forssido

Like most countries in sub-Saharan Africa, Ethiopia's economy is heavily dependent on agriculture in terms of livelihood for the great majority of the Ethiopian people, contributions to gross domestic product, and foreign exchange earnings. Unfortunately, and not unlike in many other sub-Saharan African countries, agriculture in Ethiopia is constrained by natural and man-made problems. Uncertain climate, land degradation, natural disasters such as locust and other pest infestations, drought, high population growth rate, and civil strife have been long-time features that have aggravated food deficits. As the result of these multifaceted problems Ethiopia has been facing, it has become difficult to feed the ever-increasing population.

At the sectoral level, the major issues of agriculture are the long-term decline in the agricultural resource base, food self-sufficiency, and competitive advantage. Because agricultural technology has remained stagnant and because of the pressure exerted on the land by the growth of population and deforestation, the fertility of land under cultivation and grazing has declined very much throughout the country over the past decades. To make matters worse, conditions of rainfall have deteriorated in amount and distribution, in a manner suggesting trend change. Along with the deterioration of the agriculture resource base, the country's ability to feed itself has declined in terms of overall food availability. Apart from the large food deficit occasioned by harvest failures mainly due to drought, it appears that a long-term trend of decreasing yield per unit of land has set in.

Externally, the country's competitive advantage has been on the decline. In the mid-1970s Ethiopia's major exports were about one-third coffee, one-third oilseeds and pulses, and one-fifth hides and skins, whereas at the end of the 1980s the export base had shrunk with coffee accounting for two-thirds and leather for about one-fifth. Among the main factors behind the narrowing of Ethiopia's competitive advantage are problems of agricultural efficiency.

Although the overall agriculture situation in Ethiopia is sobering, that does not at all mean that there is no light at the end of the tunnel. Ethiopia has enormous potential for agricultural development:

- *Land.* The country has an area of 1.115 million square kilometers. Sixty-six percent is considered potentially suitable for agricultural production. Cultivated land accounts for only 14.8 percent of the total area, and only about 7 million hectares are cultivated in any one crop season, and 96 percent is occupied by smallholders.
- *Livestock and fisheries.* Ethiopia has the largest livestock population in Africa. This sub-sector contributes about 30 percent to the agriculture GDP and is the major contributor to the country's export

Teketel Forsido is the Minister of Agriculture of Ethiopia.

earnings, after coffee. Ethiopia also has a vast potential for fish farming. The potential annual fishery production from lakes and rivers is estimated to be as much as 40,000 tonnes.

- *Climatic features, rainfall, and water resources.* Although Ethiopia lies within the tropics, the altitudinal variations have contributed to the existence of distinct and diversified agroecological zones. The country's diverse physical features have resulted in diversified climate and soil, which in turn have made Ethiopia a habitat for a wide variety of plants and animals.

Ethiopia is also endowed with abundant water resources (7,400 square kilometers of lakes, and 7,000 kilometers of rivers), which provide extensive potential for irrigation and fish farming. The potential for irrigated agriculture is about 3 million hectares.

Among the reasons for the very poor performance of the agricultural sector in Ethiopia is neglect by previous regimes. Mainly for this reason, domestic food production decreased by 1.1 percent per annum in the past decade and, as a result, per capita food production dropped by 4.3 percent.

The changes in the political and economic situation of the country that have taken place since 1991, the restoration of peace and political stability, the introduction of new economic policy measures, such as the liberalization of investment and trading activities, have brought improvements to the agriculture sector.

In particular, the government has taken commendable measures in terms of developing policies that would encourage agricultural development in this country. The agricultural policy of the government is an essential component of the economic policy of Democratic Republic of Ethiopia, which recently took power from the former Transitional Government of Ethiopia.

The development strategy of Ethiopia has a long-term perspective of about two decades. The long-term objective of development in this country is, in fact, structural transformation of the economy in which the relative weight of agriculture, industry, and services changes significantly toward the latter two. Indeed, the objective is to raise the share of the industrial sector in the economy both in output and employment. What is to be noted is that this structural transformation is envisaged to occur with a high growth of agriculture that is superseded by growth of industry and services.

In essence the Ethiopian development strategy revolves around productivity improvement of smallholder agriculture and industrialization based on utilization of domestic raw materials with labor-intensive technology. This strategy is akin to what is known in the economics literature as agricultural development-led industrialization (ADLI), framed into the Ethiopian context. Thus, our economic development strategy envisions export-led growth that feeds into an interdependent agricultural and industrial development. In this aspect, the strategy has two layers—an outer crust of export-led growth and an inner core of agriculture-development led industrialization.

By and large, the strategy of ADLI in Ethiopia focuses primarily on agricultural development. This is to be attained through improvement of productivity in smallholdings and expansion of large-scale farms, particularly in the lowlands. The contribution of agriculture to economic development is conceived in two ways. On one side, agriculture will supply commodities for exports, domestic food supplies, and industrial output, and on the other side, it will expand the market for domestic manufactures.

The development of small-scale agriculture is envisaged to proceed in three stages. Stage one involves the improvement of agricultural practices including animal husbandry and the utilization of better seeds. Stage two consists of the development of agricultural infrastructure, such as small-scale irrigation, and the introduction of modern inputs including fertilizers and agrochemicals. Stage three relates to increasing farm size, that would take place along with the shifting of population from agriculture to nonagricultural activities. The first and the second stages are land-augmenting in that more output would be obtained from the same unit of land. Output per farm family would increase, depending on the pace of productivity improvement and population pressure on land. However, it is our firm belief that enduring sustainability of agricultural development in Ethiopia can only be secured with the realization of stage three, which is dependent on industrialization.

During the ancient regime here in Ethiopia, the landlord-tenant relationship weakened the ability of the farmer to purchase industrial goods for consumption and investment. The landlord-tenant relationship was abolished by the previous regime, but after its demise surplus output continued to be siphoned off through forced sales of agricultural products and low, fixed producer prices. Today, the farmer is a freeholder, able to sell his produce freely. There exists an appropriate institutional basis for the rural areas to constitute an important market of domestically manufactured goods.

Our agriculture sector strategy focuses on improvement of the productivity of smallholder agriculture, as I have already mentioned, while encouraging the growth of both extensive mechanized farming and intensive commercial agriculture. It will rely on adoption of appropriate macroeconomic policies, encouragement of competitive domestic markets for products and inputs, price stabilization, diffusion of suitable technology, provision of credit, rural asset building, and promotion of farmers' associations. Broadly, the aim is to attain food self-sufficiency, to reverse ecological degradation, and to raise the competitive advantage of Ethiopia's agriculture.

Over 90 percent of the agricultural output is currently obtained from smallholder agriculture. In the long term, it is expected that the share of output from commercial agriculture will increase significantly. This change in the structure of agriculture is foreseen to occur within a context of a fast growth of production in smallholdings, which will eventually be surpassed by commercial farming. What is therefore envisaged is sectoral diversification but not dualism of a modern expanding agriculture side by side with a stagnant traditional farming. Small-scale farmers are expected, and will be helped, to shift significant production toward market sales, thus reducing the current dominance of subsistence production. Therefore, there will be both growth and transformation of agriculture.

We have designed two ways in which the productivity of small-scale farmers can be raised in Ethiopia. One would be by using existing resources of land, labor, and capital in a better way through improved agronomic practices, and another, by increasing resources, essentially of capital, to introduce improved technology, be it biological, chemical, or mechanical.

Agricultural research and extension will be geared primarily to smallholder agriculture. The focus of short-term and medium-term research will be on packaging the best cultural practices for different parts of the country. On the other hand, long-term research will put emphasis on breeding of crops and livestock. The overall agricultural research undertaking will be made to fit into the path of agricultural development expected in the different parts of the country. Its primary objective will be to provide economically optimum packages of technology to smallholders operating in different farming systems.

The diffusion of such technology will be conducted on a broad basis consistent with the ADLI strategy, which makes extension service a focal point. To effectively impart knowledge and skill, the extension service will be brought nearer to the farming community by placing field-level extension workers in close proximity to farmers. The ratio of front-line extension workers to farm population will also be quickly raised from its present level of around 1:4,000, and we have already unified our extension service, changing the recent practice of having separate field-level extension workers for coffee and natural resources development.

Technology transfer in smallholder agriculture initiates acquisition of knowledge and skill as well as adoption of the desired production technique by farmers. It is obvious that, on their own, small-scale farmers will not be able to purchase the necessary agricultural inputs that will be required to bring about technical change. However, the provision of credit is also not easy because of its administrative cost and the risk of default. To meet this challenge, various institutions and mechanisms at both ends of providing and receiving credit are being created and promoted. The establishment of rural banks and financial institutions is being actively encouraged as is the creation of farmer's associations and groupings. Even at present there are some farmer organizations and groupings who borrow themselves or act as a transmission mechanism for borrowing and repayment by their members.

Our strategy to develop small-scale agriculture also includes the building of rural infrastructure. This will include soil and water conservation measures, afforestation, physical infrastructure for tackling erosion, regeneration of pasture, improvement of the availability of water to increase production, and feeder-road construction. The strategy also includes the expansion of irrigated agriculture along with water management and protection against health hazards.

Until the establishment of the Transitional Government of Ethiopia in 1991, private commercial farming was virtually banned since the private sector was denied access to rural land. This restriction has been removed, and land that is considered unoccupied is being made available to the private sector, the conditions of land use, length of lease, and modality of allocation have been detailed, or are at the final stages. The government also encourages the export of agricultural output by ensuring quality of products, consistency of outputs, efficiency of marketing, and price competitiveness.

Before I conclude, I would like to indicate that several agricultural sub-policies have already been drawn up and their implementation is in progress. To mention only few, we have now a national agricultural research policy, a national seed industry policy, a national fertilizer policy, and a national agricultural extension system. Concerning the latter we have now embarked upon the popularization of agricultural extension packages developed for the various agroecological zones in the country. Our extension package popularization program relies heavily on large-scale, on-farm technology demonstration plots, which we have found to be very effective for educating small-scale farmers. Our experience in working with the SG 2000 project in Ethiopia for the last 3 years has provided us with an invaluable lesson in disseminating locally available agricultural technologies to farmers. We have emulated the SG 2000 approach in many parts of the country with our own funds, and I am glad to tell you that results so far achieved have greatly raised the hopes and aspirations of the Ethiopian small-scale farmer.

As part of our vigorous efforts to solve the nation's food insecurity, we have already launched a national extension intervention program in a total of seven regions, 38 zones, and 229 districts in 1995, and more regions will be included in the coming years. The number of farmer-managed half-hectare demonstration plots conducted in 1995 reached 40,000, and this number will be expanded tenfold in the next cropping season.

I would like to extend my appreciation and thanks to the sponsors of this exemplary nongovernmental organization, the late international philanthropist, Mr. Ryochi Sasakawa, President Jimmy Carter, and Dr. Norman Borlaug.

I am sure the Sasakawa-Global 2000 project activities will continue to support Ethiopia's sincere effort to become self-sufficient in food crop production and to do away with food aid in the shortest time possible.

An Overview of the Sasakawa-Global 2000 Project in Ethiopia

Marco Quiñones and Takele Gebre

Ethiopia, with a land and water mass of 1.1 million square kilometers, is the ninth largest country in Africa. It is also the third most populated and among the poorest nations in the continent (Ministry of Agriculture 1995).

Ethiopia was food secure until the 1960s, but since the drought of 1975, significant volumes of food have been imported (mainly as aid) every year. During the 1980s, domestic food production was on average only 70 percent of the recommended minimum food intake. Including food aid, food availability rose to only 76 percent of the recommended intake. As much as 50 to 60 percent of the population who live below the poverty line did not have access to adequate food. Not only has food production been low for many years, even more alarming, it continues to decline relative to population growth. FAO (1995) estimates that food import needs will grow at 6 percent per year, reaching 2.5 million tonnes by 2010.

Table 1 compares the current status of population and other basic indicators in Ethiopia and some other countries of sub-Saharan Africa.

Agricultural Profile

Sixty-six percent of Ethiopia's land area is potentially arable, yet only about 7 million hectares are cultivated in any given year (Ministry of Agriculture 1995). Around 95

Table 1. Some development indicators for selected African countries.

	1992			1991-92	
Country	Population (millions)	GNP ($/capita)	1979-92 food production growth (%/capita/yr)	Fertilizer consumption[a] (kg/ha)	Food aid in cereals (000 t)
Nigeria	101.9	320	2.0	13.3	0
Ethiopia	54.8	110	−1.3	7.1	963
Sudan	26.5	–	−2.2	7.2	481
Tanzania	25.9	110	−1.2	15.3	15
Kenya	25.7	310	0.1	39.1	162
Uganda	17.5	170	0.1	0.2	25
Mozambique	16.5	60	−2.1	1.6	591
Ghana	15.8	450	0.3	2.9	184
Ivory Coast	12.9	670	0.1	10.4	37
Cameroon	12.2	820	−1.7	2.6	8
Zimbabwe	10.4	570	−3.3	52.8	116
Burkina Faso	9.5	300	2.8	7.2	–
Malawi	9.1	210	−5.0	44.7	321
Mali	9.0	310	−0.9	7.1	36

Source: Sasakawa-Global 2000 African program country data sheets, 1995.
a\ On arable land.

Marco Quiñones is Project Country Director and **Takele Gebre** is National Project Coordinator, Sasakawa-Global 2000, Addis Ababa, Ethiopia.

percent of the cultivated land is under small-scale agriculture. The rest is under state farms and large-scale commercial farms.

Ethiopian agriculture is dominated by small-scale, resource poor farmers, most of them holding only 1 to 2 hectares. Until the present, the use of agricultural inputs (such as fertilizers, improved seeds, and agrochemicals) by small-scale farmers has been low for several reasons—inputs are rarely available near the farm gate, they generally are expensive, and credit mechanisms are yet to be put in place on a formal and sustainable manner. Ethiopian farmers consume on average only 7 kilograms of fertilizer nutrient per hectare of arable land, and only 2 percent of Ethiopian farmers use improved seed (Stroud and Mulugetta 1992), one of the lowest rates in Africa.

As the result of low and stagnating agricultural production, in large part due to limited access to inputs and other modern agricultural technologies, farming in Ethiopia has remained at the subsistence level for several generations. Traditional farming systems are not only low yielding, they also result in the mining of the main plant nutrients from the soil. Shortages of household fuel forces most farm families to collect and burn dung, weeds, and crop residues. Such practices further deplete the soil organic matter content. In addition, land-poor farmers often expand cultivation to more fragile lands. Cultivating highly erodible hillside soils aggravates water runoff that increases soil erosion.

Fragility of the soils and incorrect soil fertility management are two of the main factors constraining agricultural production.Because of high population growth and reduced food production, the gap between production and consumption continues to increase. In recent years, large volumes of food aid have prevented food shortages comparable to those that occurred during the drought of 1984/85. But reliance on food aid from donors is not sustainable, and commercial food imports require large sums of foreign exchange, which the country cannot afford. Clearly the solution is a rapid expansion in foodgrain production. Targeted areas should be located where the agricultural potential is high, rainfall is adequate, and farmers have access to national markets. Expansion in food production through productivity improvements would not only help reduce food deficits, but would also stabilize the price of food for both rural and urban consumers. In low potential areas, the government could carry out investments that would create sources of income to ensure that those who need food can afford to buy it.

The Sasakawa-Global 2000 Project in Ethiopia

The Sasakawa-Global 2000 project in Ethiopia is the continuation of an initiative that began thanks to the vision and philanthropic assistance of the late Ryoichi Sasakawa. Project activities continue to be supported with the same enthusiasm by his son, Yohei Sasakawa. We are grateful to both of them.

The work of the Nippon Foundation is complemented by the collaboration of the Global 2000 initiative chaired by former U.S. president Jimmy Carter. He works tirelessly alongside African leaders in identifying and forging government policies that are critical for promoting and sustaining economic development, health, education, and, particularly, agricultural development.

The SG 2000 projects in the field are led by Norman Borlaug, winner of the 1970 Nobel Peace Prize. Dr. Borlaug has always been a source of inspiration for all of us who work at the grassroots level under his leadership.

In 1993, SG 2000 initiated a collaborative agricultural project with the Transitional Government of Ethiopia, which has the following objectives:

- To assist Ethiopia's efforts to increase agricultural production through an aggressive technology-transfer program that will disseminate improved production technologies to small-scale farmers through the extension service of the Ministry of Agriculture.
- To strengthen the capacity of the extension services for expedient dissemination of proven, research-led technologies to small-scale producers, particularly in food crops.
- To invigorate the linkages between research and extension in order to streamline the process of technology generation and dissemination, and to provide appropriate feedback to research for technological interventions when necessary.
- To extend, through the extension services, improved grain storage and preservation technologies as well as agro-processing techniques suitable for small-scale producers.
- To identify socio-economic and other constraints to agricultural development and to evaluate alternative means of alleviating these constraints through technological and institutional changes.
- To offer the Government of Ethiopia the capacity of the Carter Center in fostering sound agricultural policies that can help sustain agricultural development in the country.

In discharging its mandate, the project has developed a series of interventions designed to strengthen the capacity of the national extension services for technology dissemination to the farming community. Its major elements are described below (Habtemariam 1995).

SG 2000 Management

For its technical field activities, the project makes full use of the extension staff of the Ministry of Agriculture and regional bureaus of agriculture. The project has established a small financial administration unit to avoid bureaucratic government financial administration. The major cost components of the project are:

- *Transport.* The project provides limited logistic assistance to extension at the central and regional levels. To a lesser extent, logistic assistance is also provided to research for testing improved technologies in farmers' fields. Usually, the project supplies double-cabin, four-wheel-drive pick-up trucks at central, regional, and zonal levels. In addition, motorcycles are provided to district supervisors, and bicycles are given to front-line extension agents.
- *Input cost for demonstrations.* To empower extension agents with the necessary inputs to implement demonstration plots, the project buys inputs such as seeds, fertilizers, and agrochemicals and makes them available to farmers at cost.
- *Operating costs.* Important expenditures in the field program include field supervision and field days. The main budget items are per diem and running costs of vehicles, including repair and maintenance.
- *Training.* An important part of the budget goes to seasonal classroom training and hands-on field training, as well as to field tours and workshops. Also, the Sasakawa Africa Association awards scholarships for

B.Sc. and M.Sc. studies at Alemaya University to extensionists who have distinguished themselves in discharging their duties.

- *Incentives.* A small budget allows the project to offer awards to the best farmers and extension staff. These awards are made in kind rather than as cash. For farmers, production inputs or oxen are the prizes, while for the extensionists, study tours are being considered.

Extension Production Demonstration Plots

Realistic Size. Traditionally, the extension services have established field demonstrations relying on what are known as small-plot adoption trials. The harvest obtained from small plots usually cannot be measured in quintals or tonnes and hence extensionists must extrapolate the numbers to make the results meaningful to the farmer. The size of SG 2000 demonstration plots—Extension Management Training Plots (EMTPs)—is approximately one-half hectare, and thus they mimic farmers' real conditions. When small farmers do not have enough land to run an EMTP, they usually join land with their neighboring farmers to attain the half hectare. EMTPs are also implemented in clusters or blocks and, because of their size, they attract the attention of farmers in the community. The commercial-sized plot not only leads to a realistic test of the technological package being demonstrated, it also affords the participating farmers an immediate economic benefit for their labor.

Availability of Production Inputs. An extension approach that relies mainly on transfer of messages or information cannot by itself provide enough basis for adoption. The SG 2000 approach makes production inputs physically available to contact farmers. The extension agent, once he has secured the acceptance of the package by the farmer, is further expected to confirm the implementation of the package in the half-hectare EMTP. It is on this basis that SG 2000 stresses the importance of integrating information with physical provision of inputs during extension work.

Financial Self-reliance. Participating farmers are required to pay 50 percent up front for the inputs they receive. They pay the rest after harvest. In addition to enhancing self-reliance, partial cash payments induce farmers to give more attention to the implementation of the technological package in order to reduce risk.

Participation. Demonstrations are conducted on farmers' own plots, and the management of the plots is their responsibility, though they are backstopped by the extension agent. Under the former extension system in Ethiopia, the demonstration plots were very small (usually 10 × 10 m) and were often managed by the extension agent who would invite farmers to learn by observing the results attained. The idea of the new approach is that by letting farmers conduct the large demonstrations on their own, they will not only evaluate the technologies but will also improve their crop management skills. Under the previous approach, they had a more passive role in technology evaluation.

Hands-on Practical Training. The project is engaged in providing both classroom and hands-on field training to grassroots extension agents, supervisors, and subject-matter specialists. The training is done on practical field operations, and it is complemented by field days, workshops, and study tours.

Role of Research. Extension recommendations are not developed without the inputs from researchers. Before each crop season begins, researchers and extension staff meet and discuss technology recommendations. Research-extension linkages are also enhanced because both institutions cooperate in:

- joint definition of recommendations
- joint visits to EMTPs and on-farm research trials
- participation in review meetings
- informal consultations and task sharing

The project plays the role of a catalyst and facilitator by allocating funds for the linkage activities. Improved research-extension linkages are essential for refining current technologies and assisting researchers in the identification and development of practical solutions to farmers' problems.

Implementation of the Field Program

The EMTP program started in 1993 when 161 demonstration plots were implemented in two regions of the country. The crops involved were maize and wheat. In 1994 the program grew nearly tenfold to 1,474 EMTPs in four regions of the country. In addition to maize and wheat, sorghum and teff (*Eragrostis teff*) were included in a small number of demonstrations. During 1995, the field demonstration program was expanded to 3,211 EMTPs (table 2).

The growth in EMTPs in each region reflects an increase in the number of zones, districts and villages included within each region, as well as an expansion in the number of participating farmers per village. There are, however, guidelines to limit the number of EMTPs per village to an amount that will trigger a rapid adoption rate within the community, while avoiding excessive numbers of plots. Usually 30 to 40 EMTPs per village are implemented during the second and third years. At the end of the second year, the first-year participants are considered graduates, and after the third year, all the farmers are graduates. In other words, a village has EMTPs for 3 years, but individual farmers take part in them for only 2 years. By the second year, some neighboring farmers already are buying their own inputs and starting to copy the EMTPs, either by calling on participating farmers for tips or by receiving direct advice from the front-line extension agents. The program moves on to new villages after completion of 3 years. By then the farming community has seen the new technology on participating farmers' fields, and after field days and farmer-to-farmer discussions, they can decide whether the new technology makes sense or not.

Table 2. Distribution of EMTPs by regions and crops, 1993 to 1995.

Region	Zones (no.)	Crop	EMTPs (no.) 1993	1994	1995
Oromia	6	maize	60	461	1,126
	6	wheat	63	462	808
	2	teff		20	90
	2	sorghum			40
Southern	4	maize	38	317	546
	3	wheat		41	67
	1	sorghum			5
Amhara	1	maize			60
	2	wheat		125	221
	2	teff			45
	1	sorghum		8	30
Tigray	1	maize		20	63
	1	wheat		10	40
	1	teff			40
	1	sorghum		10	39
Total			**161**	**1,474**	**3,211**

The EMTP package of recommendations that is advanced to farmers addresses the most pressing problems that constrain farm productivity:

- Restoration of plant nutrients in the soil by adding moderate amounts of chemical fertilizers
- Use of seed of improved high-yielding varieties
- Optimum plant populations
- Timely weeding, pest control, and harvesting

When farmers use the production inputs and good husbandry practices, as recommended by research and extension, their yields can easily be double or even triple as compared with traditional farming practices.

Profitability Assessment

Maize. Average maize yields from EMTPs[1] have consistently outperformed farmers' traditional plots by an average of more than 200 percent in 1993 and 1994. Grain yields from individual farmers varied widely across environments, reflecting both climatic differences (i.e., patterns of rainfall) and differences in management skills. Even at the same location, differing management capabilities of individual farmers resulted in significant variations in yields. Notwithstanding these variations, improved husbandry always resulted in much higher yields than traditional husbandry practices. This was true for even marginal growing conditions (table 3).

Partial budget analysis, using the 1994 average yield data, shows the high profitability of the technology (table 4). Marginal rates of return to additional investment were 565 percent.

Table 5 presents the profitability of maize production under three different scenarios: (1) assuming a 20-percent yield reduction

Table 3. EMTP average maize yield compared with traditional yield.

	Farmers (no.)		EMTP (t/ha)		Traditional (t/ha)	
Region	1993	1994	1993	1994	1993	1994
Oromia	60	461	5.1	5.5	1.6	1.6
Southern	38	317	4.9	5.5	1.6	1.6
Tigray		20[a]		3.5		0.9

a\ Yield recorded from nine farmers only.

Table 4. Partial budget analysis of maize EMTPs.

	Cost (EB/ha)	
Description	Traditional	Improved
Cultural practices		
Tilling	300	300
Furrowing	–	40
Planting	40	80
First weeding	120	60
Sidedressing	–	30
Second weeding	20	20
Harvesting	40	60
Shelling	130	200
Total labor cost	650	790
Inputs		
25 kg of seed	25	58
100 kg DAP	–	178
100 kg urea	–	168
180 g Marshal	–	70
Input delivery	–	20
Total production cost	675	1,284
Average production (t/ha)	1.5	5.5
Gross revenue (grain + straw) (EB)	1,600	5,650
Net revenue (EB)	925	4,366
Cost diff. due to technology (EB)		609
Add'l income due to technology (EB)		3,441
Marginal rate of return (%)	137	565

[1] During the 1994 crop season, nearly 40% of all participating maize growers provided actual grain yield data since their harvests were mechanically shelled.

from the current improved practice, (2) 20-percent yield reduction and no input subsidy, and (3) 20-percent yield reduction, no input subsidy, and a 10-percent fall of farm-gate grain price. Even under the third scenario, maize production would be considered highly profitable.

Wheat. In 1994, 638 farmers participated in wheat EMTPs. Out of this total, 187 farmers planted the crop on heavy clay vertisols, while the rest farmed under more favorable loamy and sandy loam soils. Since these two agroecologies are very distinct, and offer different opportunities for development, the results are reported separately.

Wheat Production on Vertisols. Ethiopia has about 7.6 million hectares of highland dark clay soils, collectively known as vertisols. The tendency of these soils to become waterlogged if not properly drained limits to their use.

Vertisols are at present used mainly for grazing and are agriculturally underutilized because of the waterlogging effect on crop yields. However, if properly managed, they represent the biggest asset of Ethiopian highlands for low risk, high output productivity.

The Ethiopian government in 1986 established a Joint Vertisol Project (Tekalign et al. 1993) with the aim of improving traditional agricultural production on vertisols. However, unimproved, low yielding technologies continue to be used by farmers.

SG 2000 has promoted the use of a broadbed-maker that was developed and field tested collectively by the International Livestock Research Institute, Ministry of Agriculture, Institute of Agricultural Research, and Alemaya University of Agriculture through the Joint Vertisol Project. With the help of this

Table 5. Per hectare profitability of maize production under different production scenarios.

Scenario	Estimated cost of production (EB)	Avg production (t/ha)	Gross revenue (EB)	Net revenue (EB)	Cost difference (EB)	Additional income (EB)	Marginal rate of return (%)
Adjusted yield (20% lower) / with current input subsidy	1,284	4.4	4,550	3,266	609	2,341	384
Adjusted yield / no input subsidy	1,384	4.4	4,550	3,166	709	2,241	316
Adjusted yield / no input subsidy / 10% fall of farm-gate grain price	1,394	4.4	4,110	2,726	709	1,801	254

Table 6. Wheat EMTPs: Average yield on vertisols, 1994 season.

Region	Zone	Farmers (no.)	EMTP Yield (t/ha) Avg	EMTP Yield (t/ha) Range	Traditional yield (t/ha)	EMTP increment over traditional (%)
Oromia	W. Shoa	82	1.90	0.8-3.8	0.60	216
Amhara	N. Shoa	105	2.60	0.3-4.5	1.40	85
Total			2.30		1.05	120

implement, farmers can make broad, raised beds, which help to improve internal soil drainage. Although grain yields from vertisols are usually lower than yields from other soil types, improved drainage can boost yield levels several-fold.

Results attained by the 187 farmers who participated in the SG 2000 wheat program are presented in table 6.

There was considerable variation in yields attained by individual farmers. This variation resulted mainly from the different levels of efficiency in promoting internal drainage. Some farmers who crop land at the bottom of a valley, normally suffer excess waterlogging as rainwater runoffs from upper plots deposit on the lower lying soils. There is an urgent need for a more permanent drainage network encompassing each of the drainage basins of the Ethiopian highlands. This network would minimize soil erosion from water runoff and would protect the farmers on the low-lying areas from receiving excessive water accumulations due to unregulated runoffs.

Table 7 presents the cost of the recommended wheat production package on vertisols. Wheat production is marginally profitable under traditional practice (MRR = 100%) but can be quite profitable under improved management (MRR = 285%). However, close to 70 percent of the production costs under traditional farming and 42 percent under improved management represent gainful employment for the farm family. Considering this, it thus appears that wheat production on vertisols can become quite profitable. Furthermore, available technology has the potential to still increase productivity above the 3 t/ha average if properly implemented. The highest yield SG 2000 farmers attained on vertisols was 4.5 t/ha. Under this production scenario, wheat farming would become highly profitable.

Wheat Production on Non-Vertisols. Wheat production in Ethiopia is mainly practiced on nitosols, and loamy or sandy loam soils. Durum and breadwheat cover around 650,000 to 700,000 hectares each year. Average yield stands at 1.29 t/ha (FAO 1993).

Traditional wheat production is subjected to many constraints resulting in very low productivity. In general, small-scale farmers use little or no fertilizer to restore soil

Table 7. Partial budget analysis of wheat EMTPs on vertisols, 1994 season

	Cost (EB/ha)	
	Traditional	Improved
Cultural practices		
Tilling	300	300
Broadcasting seed	10	10
Broadcasting fertilizer	–	10
Incorporating with broadbed-maker	–	40
Weed control	150 [a]	10
Swathing	40	60
Transporting to threshing area	15	25
Threshing	30	60
Winnowing & bagging	20	40
Total labor cost	565	555
Inputs		
Seed	262	345
100 kg DAP	–	178
100 kg urea	–	168
Herbicide for broad-leaved weeds	–	80
Total production costs	827	1,326
Average production (t/ha)	1.05	2.30
Gross revenue (grain + straw) (EB)	1,675	3,600
Net revenue (EB)	848	2,274
Cost diff. due to technology (EB)		499
Add'l income due to technology (EB)		1,426
Marginal rate of return (%)	100	285

a\ Hand weeding.

fertility. Most soils in Ethiopia will respond very positively to applications of N and P_2O_5 fertilizer. However, small-scale farmers have been unable to use fertilizer regularly because of their lack of purchasing power and the unreliability of the supply. Additionally, weed infestations (both broad-leaved and grasses) tend to decrease wheat yields.

In many areas such as Arsi, Bale, and Gondar where prolonged wheat monocropping prevails, grasses like wild oats, *Snodonia* sp. and *Lollium* sp. have become widespread weeds that threaten wheat production. Another important constraint is the genetic make-up of the varieties grown by farmers. Some of the varieties are old land races, prone to lodging, late-maturing, and susceptible to diseases such as rusts or smuts. Their genetic yield potential is low. Even when modern, high yielding genotypes are grown by farmers, they become contaminated with weed seeds after a few seasons, due to lack of an efficient seed supply system. Also, because Ethiopia is one of the secondary centers of wheat evolution, there is a very wide array of pathogenic microorganisms that renders new resistant cultivars susceptible within a short time. Thus, there is an urgent need for research to continually test and release new genotypes to replace the susceptible ones and for development of a dynamic seed system to get improved varieties into farmers' hands.

During the 1994 crop season, 451 wheat EMTPs were planted on non-vertisols in most of the important wheat-growing regions of the country. Table 8 presents their distribution by regions and zones, yield data, and comparisons to traditional practices. The overall average yield of EMTP farmers was 115 percent above the traditional average. The considerable variations of the range in yields is perhaps more important. Without exception, the low yielding plots had heavy infestations of grasses that prevented farmers from attaining better results. The SG 2000 program is designing some strategies to cope with this problem. For example, in the 1995 wheat field program, instead of conventional broadcast seeding, row seeding was used in some wheat plots to facilitate hand weeding.

The partial budget analysis presented in table 9 shows that wheat production under traditional practice is marginally profitable, unless we see it as an exercise to provide

Table 8. Wheat EMTP yield compared with traditional yield on non-vertisols, 1994 season.

Region	Zone	Farmers (no.)	EMTP Yield (t/ha) Avg	EMTP Yield (t/ha) Range	Traditional yield (t/ha)	EMTP increment over traditional (%)
Oromia	Arsi	140	3.2	2.0–6.0	1.5	113
	Bale	100	3.4	1.0–6.0	1.2	183
	E. Shoa	80	2.7	1.2–4.9	1.7	59
	E. Wollega	60	2.5	1.0–4.8	1.0	150
Southern	Hadya	41	2.7	0.8–5.5	1.6	69
Amhara	N. Shoa	20	3.1	2.6–4.0	1.2	158
Tigray	Central	10	1.7	1.0–2.3	0.7	143
Total			3.0		1.4	115

employment to the farm families. On the other hand, with improved management and the use of inputs, such as improved seed, moderate amounts of fertilizers, and herbicides for both broad-leaved weeds and grasses, wheat production is quite profitable (MRR = 315%).

Teff. Based on area sown, teff is the most important cereal crop of Ethiopia. It is also, one of the preferred staple foods. Unfortunately, it has the lowest productivity among all cereals grown in Ethiopia. The national average yield stands at around 0.78 t/ha. There are many reasons for this low productivity, among which perhaps the most important are the low soil fertility under which the crop is grown and the low yield potential of the varieties. Even when farmers apply moderate levels of fertilizers, the crop may respond by lush growth that leads to pre-harvest lodging and shattering and thus lower yields.

Table 9. Partial budget analysis of wheat EMTPs on non-vertisol soils, 1994 season.

	Cost (EB/ha)	
Description	**Traditional**	**Improved**
Cultural practices		
Tilling	300	300
Broadcasting seed	10	10
Broadcasting fertilizer	–	10
Covering	40	40
Weeding	150 [a]	10 [b]
Swathing	40	60
Transporting for threshing	15	25
Threshing	30	60
Winnowing & bagging	20	40
Total labor cost	605	555
Inputs		
Seed	262	345
100 kg DAP		178
100 kg urea		169
Herbicide: Broad-leaved weeds		80
Grass weeds		235
Total production cost	867	1,562
Average production (t/ha)	1.2	3.0
Gross revenue (grain + straw) (EB)	1,900	4,650
Net revenue (EB)	1,033	3,224
Cost diff. due to technology (EB)		695
Add'l income due to technology (EB)		2,191
Marginal rate of return (%)	120	315

a\ Hand weeding.
b\ Labor cost only.

In 1994 SG 2000 sponsored some 20 teff EMTPs in two woredas, Ada and Lume of Eastern Shoa, Oromia Region. Although, overall results were not spectacular, farmers who participated were able to increase their average yield by 50 percent above the average yield of neighboring farmers. Some modifications in the recommended package have been made for implementation in the 1995 crop season.

Sorghum. Sorghum is the "poor farmer's" crop, usually grown under environments where maize and other cereals fail. In many areas where this crop is planted, farmers not only must cope with unreliable rainfall, poor soil fertility, and tall, low yielding varieties, but also with striga (*Striga hermonthica*), a parasitic weed that often depresses sorghum yields drastically.

SG 2000 planned to implement close to 100 EMTPs during 1994. However, lack of adequate rainfall prevented many farmers from sowing the crop. At the end, only 36 plots were harvested due to insufficient rainfall or infestation by striga. Yields obtained from these plots were little different from yields from other farmers' plots. During 1995 crop season, SG 2000 has continued assessing the possibilities of improving sorghum yields by looking at varieties and management practices that can adapt better to the short-season, drought stress, and striga infestation.

Loan Recovery

Since its inception, the policy of SG 2000 has been to lend participating farmers 50 percent of the cost of inputs. Therefore, prior to the season, payment of 50 percent of cost of inputs was collected. At the end of the season, during the marketing of the produce, farmers were expected to settle their debts. For the 1994 crop season, loan recovery of 96 percent was achieved. Most farmers who did not settle their outstanding debt had valid reasons, like complete crop failure due to sowing the crop on very acidic soils or losing the crop to bush fire prior to harvesting. In general, however, one can say that as farmers become more productive, the risk of loan defaults diminishes. Of course, there will always be farmers who, in spite of achieving very high yields, are reluctant to pay, because they have been accustomed to free aid from government and international organizations. This dependency syndrome, the result of humanitarian relief work done by scores of international organizations in the past, needs to be eradicated.

Post-harvest Program

Grain losses from pests, vermin, and disease-producing microorganisms like fungi can be experienced at harvest, during transportation, drying, shelling, and storage. Depending on the efficiency of the handling, processing, and conservation techniques used, post-harvest grain losses may be minor or very severe. Because significant gains in crop yields could be nullified if inappropriate and unreliable methods are employed to handle and process the grain along the post-harvest pipeline, SG 2000 Ethiopia has included a post-harvest component as part of its field activities.

During the 1994 crop year, SG 2000 investigated post-harvest problems as a baseline for future interventions. Several villages were surveyed and a questionnaire was used to collect relevant information.

Data collected during the surveys show that farmers are very much aware of post-harvest losses. Since they can do little to ameliorate this problem, they prefer to sell much of their harvest as soon as possible, thus foregoing the possibility of storing the grain to capitalize on better prices later on. The survey and field observations also show that grain losses from attacks of insects such as weevils often start, when the crop still is standing in the field before harvest. Thus, delay in harvesting increases insect infestation. Poor maize shelling methods, such as beating the ears with sticks, produce kernel damage and predispose them to higher levels of insect infestation, moisture uptake, and fungal infection. Shelling on bare soil results in contamination of the grain with dirt, stones, and animal droppings.

Farmers do construct storage facilities at least to hold the produce for an intermediate period of time. However, such structures are often very unreliable, because they stand on the bare soil and have no rodent guards. Also, few farmers use actellic or similar pesticides to protect the grain during storage.

Based on these findings, SG 2000 Ethiopia, is designing a strategy geared at ameliorating these problems at homestead level.

Conclusion

The extension service of the Ministry of Agriculture in collaboration with the SG 2000 project has demonstrated both to farmers and concerned decision-makers that dramatic increases in the productivity of foodgrain crops are possible in Ethiopia.

It should be underlined that extension was able to attain this result for two main reasons. First and most important, agricultural inputs were made available for purchase by participating farmers at the place and time were needed. Second, participating farmers have been able to receive significant economic returns for the effort they have made in adopting the new technologies.

We believe that by so doing, the extension service has also demonstrated to those responsible for the development of the agricultural sector in this country that timely input procurement, distribution, and supply deserves priority attention.

The role of extension is to show the way. To sustain what has been so far achieved and to encourage more small-scale farmers to adopt improved technologies, decision-makers need to meet this tremendous challenge by doing whatever they can to ensure the timely supply of agricultural inputs and facilitating the provision of credit services. Only by so doing can they hasten the process of attaining food security and economic development in Ethiopia.

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Tailoring Agricultural Research for sub-Saharan Africa

Donald L. Plucknett

The status of agriculture in Africa remains troubling—yields of many crops are below world averages, government commitment to agricultural improvement too often appears uncertain at best, farmers have too few options, farm incomes are low. Yet is this the whole story? Are there ways for Africa to move up in agricultural productivity and profitability? Can agriculture in Africa become an engine of growth as it has been in industrial countries and in developing countries of Asia and Latin America? Can improvements in agriculture be brought about in a rational and systematic way? The answer lies in effective agricultural research that is tailored to fit African conditions and problems.

Increased agricultural production comes from new techniques or methods put into practice on farms. It is simply not possible to get much increase by using the same old plant and animal materials and the same old soil in the same old ways.—A. T. Mosher, *Getting Agriculture Moving* (Mosher 1966)

This paper explores some principles and strategies that could be followed to bring science to African agriculture, including building linkages with the global agricultural research system. Special emphasis will also be given to the complementary roles of public and private agricultural research, both of which must become more effective.

The Imperative to Improve Agriculture in Africa

Africa cannot continue to neglect agriculture and fail to lay the groundwork for its improvement. If it does, misery, hunger, and poverty-induced environmental degradation will continue. According to a study by FAO (1984) the challenge ahead for Africa is great:

> By the end of this century, the entire lands of developing countries—almost three times the present cultivated area—would barely be sufficient to feed their expected populations if traditional methods of farming continued to be used. No less than 64 countries—29 of them in Africa—would be unable to feed their projected populations from their own land resources. Some 2,450 million hectares, almost two-fifths of the land area, with 60 percent of the total population, would be carrying more people than they could support, representing a serious threat to human welfare and the environment.

A more recent study of global food needs to the year 2025, conducted by the International Food Policy Research Institute (Rosegrant, Agcaoili Sombilla, and Perez 1995), contains a sobering, even shocking message for Africa. If continued at present productivity growth rates plus projected improvements, African cereal production by the year 2025 would total 144 million tonnes. But by that time, market demand for cereals would be 173 million tonnes, of which 29 million tonnes would be met by imports. However, that estimated 173-million tonne demand was

Donald L. Plucknett heads Agricultural Research and Development International, Annandale, Virginia, USA.

based on the current—and inadequate—level of daily food supplies and not with the hidden additional demand that would exist, if today's diets were to be improved. Taking the hidden demand into account, the *annual deficit* was 125 million tonnes at an average daily diet of 2,500 calories, 185 million tonnes at 3,000 calories, and 304 million tonnes at 4,000 calories. When both the hidden demand and import needs were taken into account, the total food gap amounted to 154 million tonnes at the 2,500 cal/day dietary level, 213 million tonnes at the 3,000 cal/day level, and 333 million tonnes at the 4,000 cal/day level. The study concluded that *Africa must triple its food production, mostly by increasing crop yields at least threefold, by the year 2025.* This is a tremendous task, and it will be difficult. African countries must move now to meet it, if very serious consequences are to be avoided.

The only pathway for agricultural and economic advance open to most developing countries is the continuous increase in productivity of their land and water resources.—J. C. Madamba (Madamba 1985)

It is the thesis of this paper that the challenges facing Africa in food and agricultural production can only be met by establishing effective agricultural research and technology innovation systems in each country.

Agricultural Research as an Investment

Peterson (1976) stated the case for agricultural research well:

Agricultural research is best viewed as an investment. Real resources such as scientific personnel, laboratories and equipment, buildings, etc., are employed to produce a product or output. This output is new knowledge. New knowledge has value because it enables society to increase its total output of goods and services. In the case of agricultural research, the knowledge produced is utilized in two ways. First, it makes possible the production of new or improved inputs for agriculture. These inputs include new higher yielding varieties of crops, more productive breeds of livestock and poultry, more efficient machines and power, and yield-increasing herbicides and insecticides. Second, the knowledge can be used directly by farmers enabling them to produce more efficiently, thereby increasing output for a given level of production cost.

The value of agricultural research can be measured by the value of additional output that results from greater productivity in agricultural production. This additional output can be food and fiber, or it can be a greater output of nonagricultural products made possible by the release of conventional inputs from agriculture, mainly land and labor.

In the second paragraph, Peterson makes the connection between agricultural growth and its positive effects on the output of nonagricultural enterprises, which of course, can help lead to industrialization. This message should not be lost on African leaders or donor organizations.

The Importance of Effective, Publicly Supported Agricultural Research

Public agricultural research is essential to develop a scientific and institutional base for a country's agricultural improvement. Here the productive potential of the natural resource base can be assessed and explored, problems of crop and livestock production systems can be identified, research on priority problems can be carried out, and new technologies can be identified and tested. As agricultural transformation begins, and if suitable economic incentives are present, some aspects of agricultural improvement may be assumed by a growing private sector, often led by farmer entrepreneurs. And, as agriculture becomes more profitable, some aspects of agricultural research—notably technology innovation and development of inputs such as new seeds, fertilizers, and pesticides—will increasingly

No country has achieved substantial agricultural development without establishing and maintaining efficient governmental experiment stations for agricultural research.—A. T. Mosher, *Getting Agriculture Moving* (Mosher 1966).

be assumed by the private sector. As this occurs, public-sector research increasingly can move upstream in research to take on high priority, pre-technology research on pressing national problems. Public research can be very fruitful in starting technological improvements that lead to agricultural transformation. Then, as certain aspects of technology innovation are assumed by private research, public research can continue those aspects of strategic and applied research that the private sector cannot or will not enter, mostly for economic reasons. Eventually, in countries where successful agricultural transformation has been achieved, more research investment will be made by the private sector than by the public sector, and the resulting public-private research system will enjoy healthy, effective working relationships.

Public agricultural research has been a major force in improving agriculture in the industrialized nations and, more recently, in developing countries of Asia and Latin America. Public research has proved to be a good investment, yielding high rates of return in many studies.

High rates of return to agricultural research have been achieved in Africa. USAID has conducted studies of agricultural research projects in Africa, with impressive results.[1] So the picture is not all bleak for Africa, nor does the evidence justify the pessimism sometimes expressed concerning the potential role of agricultural research in Africa. It is true that current agricultural growth rates in some sub-Saharan countries are half or less of the 3.25 percent growth rate projected as needed to increase *per capita* incomes (TR&D 1995). And current growth rates do not give much cause for optimism in meeting the need to triple crop yields by 2025.

There are some bright spots in the yield picture. Yield growth rates for certain crops have increased modestly in several countries over the past dozen years: yams (Gabon, Nigeria, Benin, Guinea, Chad, Côte d'Ivoire, Central African Republic), millet (Tanzania, Burkina Faso, Ethiopia, Senegal), pulses (Nigeria), plantains (Uganda, Rwanda, Ghana, Zaire, Nigeria), cassava (Cameroon—highest rate of gain for the world for the period—Uganda, Nigeria, Madagascar, Zaire, Angola), maize (Cameroon, South Africa, Burundi, Ghana, Kenya, Somalia), and root crops in general (Nigeria, Zaire, Uganda). So we know agricultural research does work in Africa; the question is, how can we make it better and more sustainable?

Important Concepts Concerning Research and Technology Innovations and Their Application to Africa

The aim of agricultural research should be the transformation of agriculture to attain

[1] Table 2 of the paper by Evenson, later in this volume, shows the RORs found in a wide range of recent studies in Africa.

productive, profitable enterprises for farmers, to deliver quality products to markets, to attain lower food prices for consumers, and to achieve an increased contribution of the agricultural sector to overall economic development. This has worked elsewhere and I consider it achievable in Africa, given financial and political support and the will to make it happen. To do this, improving research capacity and effectiveness in each country will be necessary.

Types of Research Capacity That Might be Developed

Levels or Phases of Agricultural Research. Research can be carried out in several levels or phases, recognizing however that research is really a continuum of activities, from the search for new fundamental knowledge to its eventual application and use in daily life. Recent work by the International Service for National Agricultural Research probably summarizes it best (fig. 1).

Basic research (Level V) can be defined as fundamental research aimed at understanding basic concepts and advancing the state of knowledge. Basic research is the feedstock of new ideas and concepts for advances in all fields of endeavor that benefit from science, including agriculture.

Strategic research (Level IV) is essentially fundamental research that is aimed at overcoming specific problems. Fundamental research in agriculture is best classified as strategic research, because although the purpose for the research is problem solution, unless necessary fundamental research is done many major problems are unlikely to be overcome. Research institutions in industrialized or middle income countries are most likely to conduct strategic research. Some smaller developing countries may decide to conduct strategic research in specific areas where problems exist and for which effective partners cannot be found. In Africa, university laboratories should be used more often to conduct strategic research in agriculture.

Applied research (Level III) is aimed at finding a use for new knowledge coming from strategic or basic research. Applying new or existing knowledge to help improve production and farm profitability is a major activity of agricultural research, and most national agricultural research systems should aspire to conduct effective applied research so as to use scientific developments from elsewhere in improving their country's agriculture.

Adaptive research (Level II) is aimed at modifying research products and ideas that result in new technologies so these can be used in location-specific situations. Adaptive research is especially useful in finding ways to extend the range of adoption of new technologies because it concentrates on the fine-tuning of management practices that may be required to make an idea work in specific locations. All national agricultural research systems should aspire to conduct effective adaptive research.

Screening and testing (Level I) aims to test materials from elsewhere under local conditions for possible direct use. Screening and testing requires good research techniques and analytical skills to ensure its validity, but it does not require sophisticated equipment or laboratories. All national agricultural research systems, at a minimum, should have the capacity to carry out effective screening and testing. For countries that can identify ecological analogues of their own production environments, a carefully designed screening and testing system for

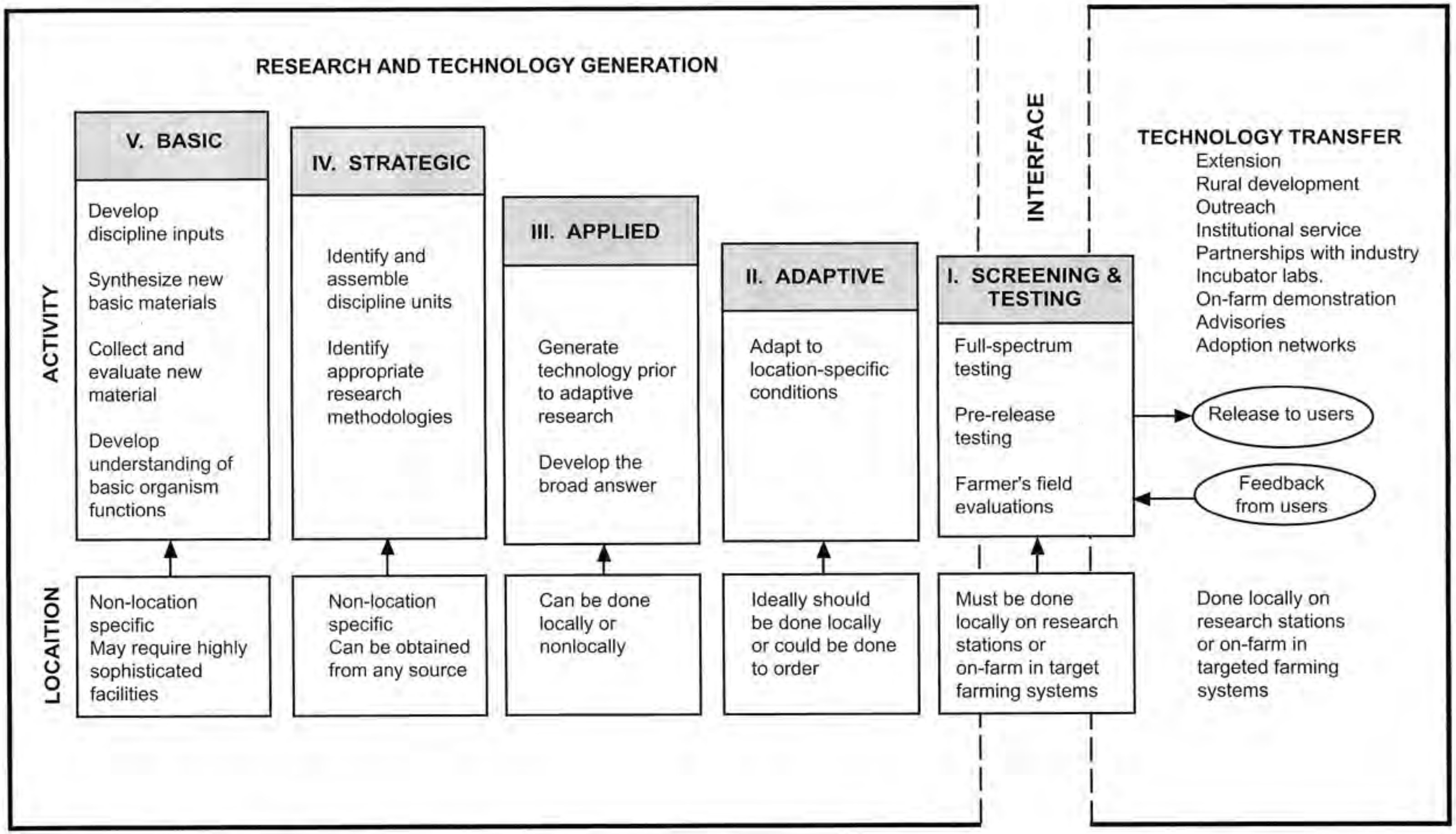

Fig. 1. Phases of agricultural research, and the research and technology generation and diffusion continuum (Source: Eyzaguirre 1991).

new technology emanating from those sources may be a cost-saving and effective agricultural research strategy.

Productivity Maintenance Research. As yields rise, it takes more and more research effort to maintain yield levels because pests and diseases and other threats are always changing and evolving, and new genetic materials and management practices will be required to prevent yields from falling back to the old, usually unsatisfactory levels. Such research has been termed yield-protecting, yield-maintaining, maintenance, or, for want of a better term, maintenance research (Plucknett and Smith 1986), or preferably, productivity maintenance research. Each country, as it goes through agricultural transformation, will find that it needs to establish a long-term, effective system of research that will help to ensure the productivity of its agricultural systems.

General Categories of National Agricultural Research System Capability

There have been attempts to categorize national agricultural research systems according to their capacity to do research and the resulting roles they may be able to play domestically and elsewhere. For example, in 1985 the U. S. Agency for International Development classified African countries as technology-adapting or technology producing (USAID 1985). Plucknett (1994) developed a typology of categories in a related fashion, using plant breeding capability as a proxy for relative stage of development of scientific capacity:

Category I. Countries that essentially do no experimentation and whose only capacity may be to serve as a generalist contact with outside research organizations. Such countries may import technology, but such imports are likely to be poorly planned and haphazard. In such countries, after proper training of local participants, only rudimentary screening and testing (Level I) might be possible but effective linkages with researchers and research developments elsewhere will be limited.[2]

Category II. Technology-importing national agricultural research systems that do limited experimentation but are restricted mostly to adaptive research (Level II) and screening and testing (Level I) and with no plant breeding capability.[3]

Category III. National agricultural research systems that import technology but also carry out screening and testing (Level I), adaptive research (Level II) and some applied research (Level III). They have some capability in selection of improved crop plants but only limited plant breeding.

Category IV. National agricultural research systems that are effectively linked into the global technology generation system, that have plant breeding capability, and that can carry out research in levels I, II, and III with relative ease.

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2 Because of lack of capacity, Category I countries must rely on technology developed elsewhere and will have little capability to evaluate that technology under local conditions.

3 Category II countries must rely mostly on technology from elsewhere, and therefore are very dependent on other countries and institutions to make sound scientific choices as to the type and direction of research, but do have some capacity to test and adapt those technologies, when available, to local conditions

Category V. National agricultural research systems that enjoy peer or near-peer relationships with international agricultural research centers and advanced research organizations in selected areas of research, and can carry out strategic research (Level IV) in selected areas when necessary. They have effective plant breeding capability, including the ability to handle and utilize basic germplasm and advanced techniques. Category V national agricultural research systems can be full partners in helping to solve pressing global or continental research problems.

How Much Research Capacity Does a Country Need?

Each country is different and may well require a somewhat different research model from others of its size. However, each country, no matter how small, needs an agricultural research capacity that allows it to *identify problems, solve important problems and provide new technologies to farmers.* New technologies may be borrowed from other countries and international research institutions, or they may be developed within the country itself.

Regarding research capacity, a useful analogy might be to compare agricultural research with human health. Each country needs a capability in public health, in preventive medicine, and in treatment of disease. Public health deals with matters of sanitation, clean water, prevention of epidemics, immunization, and so on. In cases where new health problems arise and are recognized by the public health authorities, or where more specialized medical capability is needed, outside help may be needed. In the meantime, general practitioners handle most of the health care needs for the public at large, while more difficult cases can be handled by medical specialists in major hospitals or urban centers.

To carry the analogy further, agricultural research in small countries should be able to handle matters relating both to "public health" and "general practice." Here the research capability must handle problem identification and the more immediately solvable problems. As in public health and general medicine, the more difficult problems may require attention by specialists or by referral to experts outside the country.

Developing countries need strong national research capabilities to build appropriate technologies, to adapt and apply innovations to local problems and to benefit from the results of international and regional research.—Edouard Saouma, Director-General, FAO

Many small, poor African countries are might conclude they cannot support a large agricultural research capability. But *how large is large for a national agricultural research system, and what is the minimum that might be needed?*

There are two aspects to the question of how large a national agricultural research system might be. One relates to *scale* of a national agricultural research system, which refers to the size of the overall research enterprise; the other relates to *scope* of a national agricultural research system, or the breadth and coverage of the research program (Eyzaguirre and Okello 1993). Many countries make the mistake of trying to cover all possible commodities or problem areas, and then find their existing capacity spread too thin to do effective research in even one area.

The International Service for National Agricultural Research recently completed a study of agricultural research in small countries. The study defined small countries as having 5 million people or less, and where agriculture is a significant contributor to GDP or employs a major share of the population (Eyzaguirre and Okello 1993). Fifty countries, half of them in Africa, were selected for study. Within the 50 countries, few research organizations had more than 50 researchers and most had less than 40.

Any national agricultural research system should have specialists to monitor and measure the general trends of a nation and its agriculture, serving as a kind of agricultural "health service." While being specialists in a particular field, such persons should have the capability to look broadly at agriculture in a country and assess its general status, its problems and potentials, and possible future directions, and must they understand farms and farmers. Also needed are natural resource specialists, including land and water specialists, to look widely at the natural resource endowment and help plan its wise use and effective utilization. These specialists constitute a kind of natural resources health service.

More specialized scientists are usually needed for handling specific problems of crops and livestock. Plant pathologists, entomologists, animal health specialists, agronomists, soil scientists, agricultural economists, and agricultural engineers represent core disciplines that are often required to carry out what might be termed a crop or livestock industry health service. What is needed here again is at least a minimum number of capable persons from relevant disciplines to identify problems, plan their solution, and form any necessary partnerships to carry out the needed work.

How many scientists does a small country need to handle the agricultural health service role? No fixed number can be given, of course, but probably at least three or four. For natural resource analysis and planning, the natural resources health service, there should probably be at least one soil resource specialist and one water resource specialist, but this would provide only a very minimal capability, especially in Africa where specialization in the natural resources of various districts or provinces may be needed.

In many cases, the major crops and livestock enterprises may require specialists in several fields. Hence, in a country where cassava is a major crop, a minimum-level cassava research team may require a full-time plant pathologist, geneticist/breeder, and agronomist. Also, since cassava is vegetatively propagated, one of the team should be able to do tissue-culture work, at least to receive new genetic materials in tissue culture form from abroad and grow them into plants. For livestock work, a minimum-level team might consist of a nutritionist/animal production specialist and an animal disease specialist. In all of the crop or livestock areas, some specialists may have to provide advice and to cooperate with several commodity research teams. Agronomists, soil scientists, plant pathologists, entomologists, and animal disease specialists are examples of specialties that are often shared by crop or livestock commodity research teams.

For most small countries where agriculture is important, and where the country wishes to generate at least some of its own technology, an effective agricultural research capacity (perhaps a Category III agricultural research system) may require 50 to 150 scientists. However, if a country decides that for now it can only be a technology-importing country (say a Category II national agricultural research system), an effective agricultural research system may require 20 to 40 scientists. Ruttan (1991) stated, "Even a relatively small country, producing a limited range of commodities under a limited range of agroclimatic conditions, will require a cadre of 250 to 300 agricultural scientists." Ruttan might have had in mind here at least a Category III national agricultural research system, but perhaps a Category IV research system. Eicher (1992), by contrast, states that most countries in Africa with populations below 5 million should aim for a national agricultural research system with 25 to 150 researchers, probably a Category III system in our typology. *In the end, each country will have to decide for itself what the scale and scope of its research effort will be.* Those decisions should be made within the context of a strategic planning process.

A major reference work concerning size and capacity for research in developing countries is the *ISNAR Agricultural Research Indicator Series: A Global Data Base on National Agricultural Research Systems* (Pardey and Roseboom 1989). This book has statistical information and a description for every country in Africa and will prove useful for anyone contemplating the improvement of a national agricultural research system.

African Agricultural Research Systems Within a Global Context

The Global Agricultural Research System

Little international cooperation in agricultural research occurred until after World War II. Before that time, most advances in agriculture were essentially ". . . home-grown gains, involving local scientists working on problems of national importance with tools and genetic materials that were at hand" (Plucknett 1993). It could be said at that time that most nations had to go it alone in agricultural research. Today, a global agricultural research system has developed to the point where most scientists are active in the system—or can be if they so desire—to the benefit of all. There is no reason for any country to go it alone in agricultural research and in efforts to improve its agriculture.

The global agricultural research system today consists of three main types of players—national agricultural research systems of developing countries, international agricultural research centers (IARCs), and advanced research organizations in both developed and developing countries that are involved in basic or strategic research. These players interact in a variety of ways and through various mechanisms, including bilateral and multilateral agreements, contracts, and research networks. The system was founded on scientific and research needs. No one passed legislation calling for its formation; no one appropriated funds to ensure its establishment.

The Lure of Regional Research Institutions

Regional support has received some attention as a strategy to improve regional research and development efforts, but has often proved problematical. Many countries appear unwilling to provide funding for a regional activity or entity, and even the securing of outside funding may not be enough to assure excellence or continuity in regional research programs. In some cases, help has been obtained using regional development bank funding; perhaps this strategy should be examined more in the future. Regional research in Africa could be an attractive possibility if ways could be found to make it work.

National Research Systems, IARCs, and Advanced Research Organizations

Agricultural research problems fall into three main categories:

1. *Transnational global problems,* that usually require international solutions. These are the really important ones; some of them so pressing they might be termed twenty-first century problems.
2. *Transnational continental or regional problems,* which are important on a continental or regional basis, but have not yet become transnational global problems. These need transnational solutions, usually through some kind of regional entities or cooperative efforts.
3. *National problems,* which are localized and even location-specific and which in most cases must be solved at local levels with local resources unless the national agricultural research system concerned can find outside help or collaboration.

Few small countries can afford to conduct research on all fronts. For such countries in particular, IARCs and advanced research organizations as providers of biological materials, scientific resources and research training will be required well into the future. Furthermore, considering the difficult institutional environments prevailing in many African countries, the external assistance and partnerships provided by IARCs and advanced research organizations will continue to be valuable to national agricultural research systems.

The types of contributions made by IARCs and advanced research organizations relate to the capacity and state of development of each national agricultural research system. Countries with weak research capacity, e.g., national agricultural research system categories I and II, benefit by directly adopting technologies produced by IARCs or advanced research organizations. Countries with moderate capacity (e.g., Category III national agricultural research systems) carry out some adaptive research on products from IARCs and advanced research organizations to produce their own technologies, while countries with strong research capacity (Category IV and V national agricultural research systems) are mostly interested in the ability of IARCs or advanced research organizations to act as partners in solving important problems and to deliver specialized research products that can be refined locally to meet national needs.

The global system aims to solve international problems, involving all possible players in ways that use their strengths and special advantages, without loading them with inappropriate tasks or tasks that distort or interfere with their own programs. Hence, elements of the global system have worked to test many kinds of relationships and methods to solve important problems, to transfer technology to countries and end users (farmers), to strengthen the capacity of all partners to conduct research, and *in particular* to strengthen the capacity of national agricultural research systems to carry out effective research.

Institutional Models and Funding Mechanisms

In their study of small country national agricultural research system, Eyzaguirre and Okello (1993) listed types of institutions that deal with research, including agricultural research councils, research foundations, French tropical research institutes, ministry research organizations, government agricultural research institutions, multinational agribusinesses, national agribusinesses, parastatals, nongovernmental organizations, regional organizations, regional research organizations, regional universities, and local universities. There are others that might be added, of course, including national research corporations (e.g., EMBRAPA in Brazil), individual programs of IARCs in developing countries, international or regional networks, and developed country research programs. It may be of use to discuss some of these institutional approaches in more detail.

Agricultural research council. These councils are ". . . national research coordinating and planning entities based in the public sector" (Eyzaguirre and Okello 1993). This model has been used frequently in Asia (Gapasin 1991) to help restructure agricultural research to focus on national needs and priorities, improve management of the national agricultural research systems, and coordinate and integrate the research activities of many diverse research organizations to meet national needs. Their functions may include formulating policy; coordinating research; setting priorities; dealing with program implementation; monitoring, funding, and implementing research; and managing research centers. Some councils play mostly a coordinating role, some a management role, some a monitoring role, some a funding role. In Asia, research councils have had a positive effect by helping to consolidate very dispersed research efforts, allowing a systems approach to managing and monitoring research, and creating a favorable environment for conducting research.

Research foundation. Research foundations have been adopted recently in several Latin American countries, e.g., Jamaica, Honduras, and Ecuador. Foundations have been tried partly for reasons of flexibility and ability to acquire resources not available to public sources, to increase the stability of funding for research, and to reduce the effect of bureaucracy on the necessary freedom and creativity of the research enterprise. Foundations can hire outstanding scientists and create a favorable environment for research. A major problem for foundations is obtaining secure funding. To achieve this, some type of endowment system is probably required, provided a funding source can be identified and then convinced to make such funds available.

Ministry research organization. Probably the most common form of agricultural research organization in developing countries, government agricultural research organizations can be effective or less effective, depending on national priorities relating to agricultural development, competition for funds with other public entities, stability of funding for research, and the amount of bureaucracy that may be involved in the agricultural research enterprise and its management. Too often, government agricultural research lacks imagination, is imitative, is plagued with inadequate and unstable funding, is poorly staffed and equipped, and lacks an effective incentive system for good scientists.

The challenge for African governments and those donors interested in agricultural research in the continent is how to help make publicly funded Ministry of Agriculture research and related research efforts in other ministries (e.g., in irrigation, animal health, etc.) effective.

Government research institute. In Latin America, some national research institutes have been established to take over from former government-run institutions, often to give research more autonomy from the heavy hand of government and to create a more favorable environment for research. Some government research institutes cover most of the research program for a country, while others may be more specialized. Specialized research institutes might include animal health research, pest identification and control, food processing, and research institutes related to matters such as plant or animal quarantine or genetic resources.

Specialized government research institutes may be established with good results, especially if funding is adequate and stable, good research is valued and rewarded, and bureaucracy and political interference are minimized. Although potentially important, specialized government research institutes usually constitute only a part of the total national agricultural research system capability, and might suffer from isolation from the larger enterprise unless due attention is taken to prevent it.

Multinational agribusiness. Some international corporations may have resident research capability in developing countries. Such entities are usually less interested in strategic research, for example, than in international screening and testing of new products or in adaptive research and applied research relating to product development. Included in this category could be multinational seed companies, chemical companies, machinery companies, and, today or in the near future, genetic engineering companies. Such companies add to the overall agricultural research capability of a country, but often are necessarily interested mostly in product development, testing, and marketing. Probably few such research activities are present in most African countries, except in the larger or more developed countries such as Nigeria or South Africa.

National agribusiness. Africa does have a few national agribusiness companies that conduct research, notably in seeds and other agricultural inputs. Such companies should be considered as clients and partners of national agricultural research and should not be feared or shunned, as happens all to frequently. Private businesses and their research efforts should be seen as desirable parts of the technology-transfer process and encouraged to become partners in technology generation and transfer.

Parastatal. Many parastatal organizations in Africa have become heavy burdens for the countries that support them and too often are ineffective. Parastatal research entities elsewhere—usually research units attached to commodity boards—have conducted useful research in such commodities as sugarcane, coffee, oil palm, coconut, and cocoa. So the model of a research institution supported by a parastatal organization is not inherently bad, but the performance of parastatals in Africa would have to improve before I could recommend them as a model for improving agricultural research. This is especially true if the scientists were to lose some of their freedom under less-than-friendly parastatal management. I would be more optimistic concerning the role of parastatals in francophone Africa that have working research relationships with French tropical research institutions.

Nongovernmental organizations. Some nongovernmental organizations (NGOs) have good research capability in agriculture, e.g., the Mennonite Central Committee assigns qualified staff to do screening and testing (Level I), adaptive research (Level II), and applied (Level III) research. Where NGOs have such capability they can make a real contribution. Some are more suited to village-level technology transfer where they could carry out Level I and sometimes Level II work. NGOs with capability in Levels II and III in particular could add considerable strength to technology-transfer activities in countries where only Category I or Category II national agricultural research system capability now exists.

Regional organization. Some regional organizations with broad mandates have interest in agricultural research, e.g., Inter-American Institute for Cooperation in Agriculture (IICA) and the Southern Africa Development Council and its regional research coordinating arm, SACCAR. Regional organizations effective in research coordination or implementation could play an important role in helping small countries to handle regional or continental problems that demand international solutions, however, their funding and management have proved to be problematical.

Regional research organizations in Africa are not new. The colonial period saw the establishment of a dozen or more regional research enterprises, mostly devoted to the improvement of a commodity, e.g., rice, cotton, oil palm, cocoa. Most of these regional enterprises did not long survive the flood of independence in the continent. Most troubling was the demise of the East African Agriculture and Forestry Research Organization, which had very good staff and excellent facilities. Today, French tropical agriculture research bodies work across the francophone countries, apparently with good results. The problem with regional research too often has been a lack of long-term financial support from the benefiting countries. Without that, a regional research organization becomes an agglomeration of short-term projects supported by foreign assistance funds and has little chance of surviving beyond the life of the projects.

Despite the problems, regional research in Africa remains attractive. However, I am not optimistic that a formula to make regional research work will be found, unless endowments could be found to ensure institutional autonomy and scientific excellence.

Regional universities. I am not aware of a regional university in Africa, but there are at least two elsewhere that play a role in regional research—the University of the West Indies and the University of the South Pacific. If effective, such universities could also present an attractive possibility, especially for conducting strategic research (Level IV) and applied research (Level III).

Universities. Universities in developing countries are an underutilized resource in agricultural research. Rarely are universities even considered as a part of a national agricultural research system, and seldom is university research considered an asset in national agricultural development. This is a pity, for universities have talented staff, most of whom are highly educated and trained for research. Also, postgraduate education involves rigorous research that could become a source of strategic research (Level IV) and applied research (Level III) for the benefit of the nation. What is needed is to find ways to incorporate the talent pool within the university for the good of the country. USAID recognized this in its mid-1980s effort to support agricultural research and faculties of agriculture in Africa (USAID 1985), and it attempted to link the strengthening of agricultural research capabilities with strengthened faculties of agriculture. This was a wise strategy that to succeed required a long-term commitment. Wilson (1986) recommended " . . . the transformation of National Agriculture Research Institutes, Extension Divisions, Paraprofessional / Technical Agricultural Schools and University Faculties of Agriculture into integrated/ interactive agricultural science and technology systems with social responsibility to the community for agricultural development . . . if there is the national political will to adopt such a strategy for agricultural development." This bold recommendation, coming from a professor and senior administrator in the University of the West Indies and a member of the U. N. Advisory Committee on Science and Technology for Development, should have received more attention.

I have never understood why the major educational institution in a country—the university where most researchers receive their education and qualifications for research—is not considered a key component of that country's agricultural research structure. *Integrating the universities as key components of national agricultural research systems should be a policy of all donors in their efforts to strengthen agricultural research in Africa.* Too much research talent and capability exist within the universities to be ignored any longer. If there is fear that university researchers may not work on national priority problems, that worry can be resolved quickly through a grant system that funds high priority research. University professors are as interested as any researcher, perhaps more, in obtaining financial support for their research.

Because research opportunities always exceed the funds available, resource allocations decisions must be made. Informed insight, experience, and accumulated knowledge have always formed the cornerstone of such funding decisions. Quantitative estimates of possible future benefits can serve as additional factors in making decisions. These can help in the ranking of projects, suggest where shifts in emphasis might raise total returns to research, and indicate areas where expected payoff is attractively high.

It has been found that funding for national agricultural research systems is least adequate in those countries that could potentially benefit most from increased research efforts (FAO 1985). This is particularly true for Africa. The World Bank (1982) reported that although spending on research in 51 developing had risen significantly countries during the 1970s, it was in 1980 still equivalent to only 0.5 percent of the value of the agricultural output. *For most African countries, continuing underinvestment in research has been the norm.* Table 1 illustrates the underinvestment,

Table 1. Estimates of per capita expenditures for agricultural research in selected countries.

		Expenditure (US$/person)		
	Year	Public	Private	Total
Israel	1983	10.00	na	na
United Kingdom	1995	8.40	9.50	17.90
United States	1995	6.66	13.33	20.00
Taiwan	1985	2.60	na	na
South Korea	1985	1.15	na	na
Nigeria	1983	0.90	na	na
Kenya	1984	0.67	na	na
Egypt	1984	0.50	na	na
Sudan	1984	0.35	na	na
Philippines	1985	0.18	na	na
Ethiopia	1985	0.12	na	na

Note: Estimates calculated using a variety of sources including Pardey and Roseboom 1989 and FAO population statistics.

compared with countries elsewhere. The problem is at least twofold—obtaining funds to build a competent, effective national agricultural research system and then obtaining future funds to meet recurrent costs so as to maintain the capability developed.

Organizing and Managing a National Agricultural Research System

National Research Planning

Strategic planning. A strategic plan can help a national agricultural research system in its improvement and development. I like the following definition of strategy, "An organization's strategy describes the most desirable vision of the future, outlines the essential elements of a course it intends to follow to realize that vision, and provides a justification for the identified course" (Ozgediz 1987). Components of strategy include identification of clients and beneficiaries, the external environment in which the organization will work, the internal environment, current strategy being followed, the mission of the organization, guiding values of the organization, the major "businesses" of the organization, policy choices to be made, priorities, and the operational implications of all of the above (recognizing that a strategy represents a scenario for organizational change).

Strategic planning for national agricultural research systems in Africa would include the desired scale and scope of the national agricultural research system in question, the category of national agricultural research system development desired or likely to be attained, possible partners in the research enterprise, modes of operation in research, and so on.

Priority setting. Early decisions should be made about the research priorities to be tackled by the national agricultural research system and, then, the amount of resources to be allocated to them. Small national agricultural research systems must avoid too broad a scope, i.e., taking on too many topics and in too general a way. The eminent agriculturist Richard Bradfield used to say, "There are many problems in agriculture; some of them are important." Priority setting is subjective and has many facets, but the two questions posed by Ruttan (1986) perhaps best lay out its nature: (1) "What are the possibilities of advancing knowledge or technology if resources are allocated to a particular commodity, problem or discipline?" and (2) "What will be the value to society of the new knowledge or the new technology if the research effort is successful?" From those questions, Ruttan then goes on to calculations concerning: (1) "A comparison of the ratio of research expenditure by commodity to the value added in farm production for each commodity." (2) "A comparison of the ratio of research expenditure by factor (or resource input to the cost of the factor (or resource) in production." (3) "A comparison of the ratio of research expenditure to the value added at each stage in the food production chain from purchased inputs to the consumer." (4) "A comparison of the

> *". . . agriculture was . . . the first science—the mother of all sciences; it remains the science which makes human life possible; and it may well be that, before the century is over, the success or failure of science as a whole will be judged by the success or failure of agriculture."*—Andre and Jean Mayer (Mayer and Mayer 1974)

ratio of research expenditure in each field of science to the value added for each commodity, factor, and stage."

Table 2 presents some strategic questions that a country in particular must ask in planning for the improvement of its national agricultural research system (Eyzaguirre and Okello 1993). These questions comprise a checklist any country might consider in strategic planning.

Assuring Accountability and Effectiveness

All research systems should be evaluated for their effectiveness, both as regards management of the research enterprise, including its choice of priorities, and its benefits to agricultural producers and the public at large.

Measuring capacity for agricultural research is difficult and somewhat subjective. However, the following list of indicators

Table 2. Strategic questions for research policy and administration in small countries.

Questions	Conditions
How much can a country invest in research?	• Funding as a percentage of agricultural GDP in small countries is higher on average than in larger countries—further increases are unlikely • External sources of funding are not growing • Trained human resources in science and administration are scarce and difficult to retain
How to organize and institutionalize research capacity?	• Few national research institutions are large enough to cover the breadth and scope of the problems • Many dispersed activities exist in projects, NGOs, and producers' associations • Difficulty in capturing and applying relevant information and technology from outside, and difficulty in storing and using information about resources and new technologies being tested within the country
What are the key functions to be performed by research?	• Experimentation • Managing information • Coordination • Policy advice • Regulation • Linkages
How can a realistic scope of research be set and sustained?	• Commodity domains • Natural resource problems • Socio-economics, post-harvest and marketing themes • Diverse institutions doing research within these domains
How to make the most of technologies, information, and resources from outside?	• Regional partnerships • Networking • International agricultural research centers • Donor projects • International agencies

Source: Eyzaguirre and Okello 1993.

used in Egypt to assess the development and effectiveness of a national agricultural research system (TR&D 1994) could be useful as countries attempt to assess their own national research system. The indicators are:

- Ability to deal with change
- Ability to introduce new enterprises and new technologies and to present new opportunities
- Ability to deal with emergencies
- Ability to identify important problems and constraints
- Ability to solve important problems
- Able, motivated, well-educated pool of scientists
- An institutional management capability to make the best use of available resources and to provide an environment in which scientists can make best use of their talents
- Facilities, equipment, and support sufficient that reliable research can be done and problems solved
- An institutional culture that places heavy emphasis on serving the farm and farmer
- A system that gains the confidence of the agricultural community
- International recognition and effective collaboration

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Adoption of Improved Technologies in the West African Semi-Arid Tropics: Success Stories and Challenges

Ousmane N. Coulibaly

In the semi-arid zones of Africa, the principal emphasis of technology introduction has been new cultivars and animal traction. Technology development has been very successful in the Sudano-Guinean zone, where introduced cotton and maize technologies have included new cultivars combined with improved agronomic practices and rapidly increasing levels of inorganic fertilizers. In contrast, new sorghum and millet technologies have not been successfully introduced. Farmers still use local cultivars of sorghum and millet with low levels of inorganic fertilizers.

In the Sudanian zone, early maturing cultivars of cowpea have been successfully introduced. They have spread quickly because their short growing cycle fits the short rainy season and because they are high yielding. Improved millet and sorghum cultivars promoted by extension have not been popular with farmers.

We used whole farm modeling to assess the profitability of new technologies and to look at the reasons for successful introduction and diffusion of cotton, maize, and cowpea cultivars as compared with the poor acceptance of improved cultivars of sorghum and millet.

The Regions and New Technologies Developed

The study focuses on the Sudano-Guinean and the Sudanian agroecological zones of Mali. The new technologies considered are mainly the new cultivars of millet, sorghum, maize, cowpea, and cotton combined with application of inorganic fertilizers.

The Sudano-Guinean Zone

The Sudano-Guinean agroecological region is characterized by ample rainfall, ranging from 800 to 1,200 mm per year, 9 years out of 10. It is endowed with better soils than the Sudanian region where annual rainfall is between 600 and 800 mm. Technological change has affected the Sudano-Guinean region more than other regions of Mali due to its richer resource endowment and the degree of research effort and policy attention that has been concentrated here. Higher rainfall, better soils, and institutional support have facilitated the adoption of new cultivars of cotton and maize and of associated technologies including use of inorganic fertilizers, pesticides, and improved cropping practices such as the use of animal traction for soil preparation and weeding (table 1). Animal traction is widespread—almost all farm households own animal traction equipment including at least a plow and a pair of oxen (ESPGRN 1994). Inorganic fertilizers are mainly used on cotton and maize, but this technological change has not spread to sorghum and millet, a challenge yet to be addressed by researchers, extensionists, and policymakers.

Ousmane Coulibaly is consultant, IITA Humid Forest Station, Yaounde, Cameroon.

New maize technologies were rapidly introduced during the early 1980s. By 1986 new cultivars of maize were planted on over one-third of the maize area in Mali (Sanders, Shapiro, and Ramaswamy 1995, 90). The rapid diffusion of new maize cultivars combined with inorganic fertilizers is linked to the sufficient rainfall in the Sudano-Guinean region, the availability of subsidized credit for inorganic fertilizers, and guaranteed higher prices for maize.

In the last two decades, the use of inorganic fertilizers has increased rapidly in this region but has been concentrated on high-yielding cultivars of cotton and maize. Little inorganic fertilizer is used on local cultivars of sorghum and millet, which cover more than half of the total area cropped. The central issue is why high-yielding cultivars of cotton and maize been rapidly adopted, while farmers are still using local cultivars of sorghum and millet with low levels of inorganic fertilizers.

The Sudanian Zone

The Sudanian zone is characterized by low rainfall with frequent water stress and poor soil fertility. The high inter-annual and intra-annual variability of rainfall makes crop production risky especially when local late-maturing cultivars are used. This harsh climatic environment, however, has favored the rapid introduction and diffusion of early maturing cultivars of cowpea by farmers since 1985.

The cowpea story merits some attention. Local farmers who were working part time on the agricultural research station of Cinzana (Central Mali) noticed the early maturity and high yielding characteristics of some cowpea cultivars (KN1, TN8863, TVX 3236). They "pocketed" part of the seeds and tried them in their own fields in 1984. The diffusion started informally outside the traditional extension-farmer framework. A rural development project established in the area in 1985 provided insecticides to farmers on credit. In 20 villages around the research station of Cinzana, the area planted to improved cultivars of cowpea, increased from less than 100 hectares in 1984 to 1,000 hectares in 1986 (Coulibaly 1987). This tremendous rate of diffusion dropped sharply in 1987 when rising cowpea production overwhelmed local markets.

Table 1. Present and potential crop production technologies in the main agroecological zones of Mali.

	Potential technologies	
Present technologies	**Water availability**	**Soil fertility**
Sudano-Guinean zone		
New cotton and maize cultivars with inorganic fertilizer and improved agronomic practices (animal traction).	Not high priority (Sufficient rainfall in most years)	Organic and inorganic fertilizers combined with improved millet and sorghum cultivars.
Improved agronomy and inorganic fertilization on maize.	Erosion-control devices	
Rapid increase in use of organic fertilizers.		
Sudanian zone		
Early cowpea cultivars.	Water-retention techniques.	Organic fertilizer.
Ridging (animal traction) and increases in organic fertilizers.	Earliness gives drought escape.	Improved cereal cultivars combined with moderate levels of inorganic fertilizers.

Source: Adapted from Sanders, Shapiro, and Ramaswamy 1995.

Factors Affecting the Adoption of Improved Technologies

Agroecological Conditions

The rapid diffusion of new technologies depends upon their suitability to specific agroecological niches. The spatial heterogeneity of soils, rainfall, and pests is a critical consideration in designing technologies to fit homogenous niches. Improved cultivars of cotton and maize combined with high doses of inorganic fertilizers only fit environments that have high rainfall and better soils, like the Sudano-Guinean zone. In the Sudanian zone where the cropping season is shorter, improved cultivars of cowpea are better adapted. Their early maturity helps them to escape late-season drought. Despite the adoption of improved cultivars in the Sudanian zone, most of the technological advances in Mali have occurred in the Sudano-Guinean zone where lower variability of the rainfall decreases yield variability and income risk.

Land degradation resulting from rising population pressure has led to the adoption of land-conserving technologies in the West African semi-arid tropics. An example is the use of rock bunds by farmers in pockets of intense population pressure in Burkina Faso. When land degradation became visible, farmers constructed permeable rock bunds that reduce run-off of organic matter and fertilizers, while increasing water retention (Matlon and Adesina 1991). The adoption of contour dikes and rock bunds is also going on in the Sudanian zone of Mali where land degradation and water stress are a growing threat to food security.

In Nigeria, population pressure has increased the demand for improved, early bulking cassava varieties to meet food needs. Nweke et al. (1994, 22) found that villages in areas of high population density more frequently abandon local late-bulking cassava genotypes than do villages in areas of low population density.

Early maturing cowpea cultivars adopted in the Sahel had the advantage of easing food shortages in the critical period before cereals, the staple crops, mature. Placing a premium on food available in the "hungry period," or food-shortage period, raises the rate of return on investment in improved early maturing cowpea to 92 percent (Oehmke and Crawford 1993, 9). Thus technological change has greater chance to occur in a crop that has a natural comparative advantage in the area where it fits the biophysical conditions (Coulibaly 1987; Smith et al. 1993).

Profitability

For a technology to be adopted, a minimum necessary condition is that it lowers the total cost of producing a unit of output (Binswanger 1986). Higher returns are an important factor in adopting a new technology.

In the Sudano-Guinean zone, the improved cultivars of cotton and maize are more profitable than local cultivars of millet and sorghum combined with the same levels of inorganic fertilizers (table 2). They are also more profitable than improved cultivars of millet and sorghum combined with inorganic fertilizers. The returns from improved cotton and maize cultivars are 165 and 23 percent higher, respectively, than those of improved sorghum cultivars. The same difference in profitability explains the adoption of improved cowpea cultivars versus improved cultivars of millet and sorghum in the Sudanian zone. Improved cowpea returns are 70 percent higher than the returns for improved cereals (table 2).

Outside Mali, many cases of successful technology adoption linked to profitability have been documented. The high yielding maize variety TZB of IITA has been widely diffused in the savanna zone because it yields better than local cultivars and is resistant to the fungal diseases rust, blight, and ear rot. Compared with local cultivars, TZB yielded 150 to 200 percent more in experimental trials and 21 to 115 percent more on farmers' fields. It is estimated that high yielding maize varieties are grown on more than 2 million hectares in Nigeria alone (Spencer and Polson 1991, 282). The color of the grain (white) and the high quality of the seed increased its acceptance by farmers as did the fact that maize could provide both food and cash (Smith et al. 1993, 162).

New technologies must also fit the farmer's resource endowment and management capacity. This has been an advantage of the IITA cassava variety TMS 30572, whose growing characteristics result in lower weeding labor because of its wide shading. It is also a low-risk technology because of its tolerance to pests and diseases.

Institutional Environment

Research-Extension. A well-structured and adequately funded research-extension system is a key factor in generating technologies to be adopted by farmers. The success in cotton and maize is linked to investment in research and extension. The Compagnie Française du Développement des Fibres Textiles (which later became the Compagnie Malienne de Développement des Textiles) set up a well-coordinated mechanism of research on cotton cultivars adapted to local agroecological environments. Investments in breeding and agronomic practices for cotton (tillage, fertilization techniques, and pest and quality control) have increased in recent decades and have dominated the investments on other crops. A well-coordinated extension-informal

Table 2. Profitability of crop technologies in the Sudano-Guinean and Sudanian zones of Mali (based on yield response experiment run over 9 years).

Treatment no.	Cultivar	Fertilizer (kg/ha)	Expected yields (t/ha)	Expected returns [a] (CFA 000/ha)	Change in returns [b] (%)
Sudano-Guinean					
1	Improved sorghum	150 [c]	1.34	44.8	
2	Improved millet	150 [c]	1.11	31.0	
3	Improved cotton	250 [d]	2.17	119.0	165
4	Improved maize	250 [e]	2.66	55.0	23
Sudanian					
1	Improved sorghum	150 [c]	1.36	49.0	
2	Improved millet	150 [c]	1.10	40.7	
3	Improved cowpea	100 [f]	1.28	83.2	70

Source: Coulibaly 1995.
a\ CFA 1,000 = US$2.00.
b\ Compared with treatment 1.
c\ Compound fertilizer: 100 kg/ha; urea: 50 kg/ha.
d\ Compound fertilizer: 200 kg/ha; urea: 50 kg/ha.
e\ Compound fertilizer: 100 kg/ha; urea: 150 kg/ha.
f\ Compound fertilizer: 100 kg/ha.

training-farmer system through village associations has enhanced the learning process and favored the diffusion of technologies associated with cotton.

Maize received much attention from two international agricultural research centers, CIMMYT and IITA. The high yielding cultivars of maize have been thoroughly tested to fit local agroecological conditions. The rate of return on research and extension has been estimated at 135 percent, one of the highest returns to investment in sub-Saharan Africa (USAID 1993).

Like maize, improved cultivars of cowpea (KN1, TN8863, TVX 3236) come from international research centers, especially IITA, and have been tested in different Sahelian countries by SAFGRAD (a research network) and national agricultural research systems. In Senegal the improved cowpea cultivar CB-5 has been successful because of the collaborative research, extension, and input supply efforts involving the USAID-supported Cowpea Cooperative Research Support Project, the government of Senegal, and the University of California-Riverside. The benefits to society resulting from the multi-country cowpea research and development range from US$1.3 to $12.3 million per year (Sanders, Shapiro, and Ramaswamy 1995).

IITA's research on cassava mealybug had a benefit-cost ratio of 149 by controlling mealybug in 90 percent of the cassava-growing region (Norgaard 1988), with an estimated benefit of US$3 billion to African farmers (Spencer and Polson 1991, 285). The cassava mealybug can cause up to 75 percent yield loss when the attack is severe (Dorosh 1988, 19). The success of this biological control research should encourage donors to invest in both international and national agricultural research. Stifel (1991, 119) estimated that the benefits from cassava biological control are likely to pay for the CGIAR's entire core budget in Africa for 23 years.

Access to Input Markets and Liquidity. In the Sudano-Guinean zone of Mali and Burkina Faso, the input-tied credit system and the delivery of inputs through village associations has led to the wide diffusion of animal traction and the use of high yielding cultivars of cotton and maize combined with high levels of inorganic fertilizers. Input delivery has been supported by the promotion of animal traction including veterinary services, training of local blacksmiths for maintenance of animal traction (spare parts and repairs), and construction and maintenance of feeder roads. Millet and sorghum did not benefit from the credit system, and farmers have to pay in cash for the improved technologies for millet and sorghum (seeds, fertilizers, and fungicides). Farmers cite the liquidity constraint and the lack of access to credit as major barriers to the adoption and diffusion of improved cereal technologies (Coulibaly 1995).

The importance of credit availability and access to input markets as incentives for sustained adoption of new technologies is illustrated by the withdrawal of the Malian cotton parastatal (CMDT) from the supply of input-tied credit and seeds and the marketing of maize (guaranteed prices) in 1986. The area planted to high yielding varieties of maize production shrank considerably when these policy measures were implemented. The average maize area per farm household dropped from 3 hectares in 1985 to 1 hectare in 1987 (Coulibaly 1995). The importance of access to credit and inputs in accelerating adoption of new technologies is shown in table 3. Without access to credit for cereals, farmers would continue to use local cultivars of sorghum with low levels of inputs and would not adopt new cereal technologies recommended by the extension. The access to inputs through credit would significantly increase the area in improved cultivars of sorghum and maize combined with higher levels of inorganic fertilizers.

Access to imported inputs, especially inorganic fertilizers and the fertilization of cereals becomes increasingly difficult following the recent CFA devaluation. In Mali, most subsidies were removed after the devaluation, and the prices of nitrogen and phosphorus rose by 50 percent without a corresponding increase in crop prices (Coulibaly 1995). Policies to ease the constraints for financial and input markets through the formation of rural financial institutions and the promotion of investments in infrastructure are important for the adoption and diffusion of technologies. Improvements in infrastructure reduce the costs of marketing products and inputs.

Seed Multiplication and Supply to Farmers. For sustained adoption and diffusion of improved crop cultivars, an adequately functioning seed industry must exist to increase seed production, seed multiplication, and the availability of improved seeds to farmers. In Mali, the multiplication and supply to farmers of improved cotton and maize seed have been organized by CMDT, the cotton parastatal, through village organizations, with heavy investments from the government and foreign donors. Cotton and maize seeds are included in an extension package along with fertilizers and pesticides. While cotton and maize seed multiplication and distribution are well funded, seeds of improved millet and sorghum cultivars are supposed to be taken care of by the poorly funded government seed company, which is facing drastic budget cuts. NGOs are taking over the multiplication and distribution of improved millet and sorghum seeds, but they are operating on a scale too small to meet the demand from farmers.

Output Prices and Access to Markets. Guaranteed and attractive prices for cotton and maize in the Sudano-Guinean zone have

Table 3. Access to input-tied credit and the adoption of improved technologies in Mali.

Treatment			Credit for cotton only			Credit for all crops		
		Fertilizer	Area	Returns		Area	Returns	
no.	Cultivar	(kg/ha)	(ha)	(CFA 000)	cv (%)	(ha)	(CFA 000)	cv (%)
1	Local sorghum	0	7	217	10	0	0	–
2	Improved sorghum	150 [a]	0	0	–	5	193	12
3	Improved cotton	250 [b]	4.5	657	24	4.5	657	30
4	Improved maize	250 [c]	1	56	27	5	250	6
5	Improved groundnut	150 [d]	0.75	38	3	0.5	28	3

Source: Coulibaly 1995.
a\ Compound fertilizer: 100 kg/ha; urea: 50 kg/ha.
b\ Compound fertilizer: 200 kg/ha; urea: 50 kg/ha.
c\ Compound fertilizer: 100 kg/ha; urea: 150 kg/ha
d\ Compound fertilizer: 150 kg/ha.

decreased the risk of income fluctuations and encouraged farmers to adopt the new technologies. Price liberalization could achieve the same effects if it can stabilize prices and therefore decrease the riskiness of technologies adopted. Another major factor behind the success of cotton in francophone countries, in contrast to the anglophone countries, has been the timely payment of proceeds to farmers (Lele, Christiansen, and Kadiresan 1989).

The importance of access to market and market information in sustaining technology adoption and diffusion is illustrated by the collapse of the cowpea market in the Sudanian zone of Mali. When the production of cowpea in the 20 villages around the research station reached a peak in 1987 (1,000 t), the Rural Development Project, which had encouraged the cowpea production, failed to inform potential buyers (traders) who were willing to collect all the cowpea production for export. The price of cowpea collapsed from CFA 100/kg to CFA 25/kg, causing the area planted in cowpea to drop by more than 85 percent. Availability of market outlets is critical for sustaining the adoption and diffusion of agricultural technologies.

A disincentive to the adoption of the improved millet and sorghum technologies is the collapse of grain prices during the good harvest years (years of good rainfall) in the Sahel. Prices may fall as much as 50 percent. Improved market opportunities as a determinant of intensification through adoption of new technologies is widely documented (Binswanger and McIntire 1987, Smith and Weber 1991). Early bulking cassava varieties have been quickly adopted in West African and East African villages that have better access to market where the crop can be sold to meet immediate cash needs.

Conclusion

Technology development, adoption, and diffusion requires investments in research and extension as well as the creation of an institutional environment favorable for sustaining the whole process of diffusion. The improvement in institutional environment includes access to credit and input markets, integrated and coordinated research-extension-farmer linkages, reliable markets, and marketing information. Institutions involved in the generation and diffusion of new technologies should understand the agroecological diversity and the farmers' resource endowments in order to target the new technologies to niches. The commitment of the government, the private sector, the NGOs, and farmers is crucial for generating a sustainable food and income-generating capacity through the adoption and diffusion of improved agricultural technologies.

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Successful Diffusion of Improved Cash Crop Technologies

Mohamood A. Noor

Productivity-enhancing agricultural technology has been well developed for cash crops in Africa for a considerable time. Agricultural research, which was funded by the colonial governments and managed by their research institutions, was initiated in the 1900s. These institutions focused primarily on commercial crops that were grown by European settlers and agricultural companies. The target commodities were tea, coffee, rubber, cocoa, sugarcane, cotton, dairy cattle, maize, and wheat. The last three commodities were produced by European settlers in eastern and southern Africa. Some companies also engaged African smallholders as contract farmers and provided them with planting materials, inputs, extension services, and secure markets for their produce. Beginning in the 1950s, contract farming flourished throughout Africa and complemented commercial farming considerably. After independence, the role of smallholders in cash crop production expanded even further.

At independence, there were agricultural research institutions that catered to entire regions (e.g., former British colonies of eastern and southern Africa, former Belgian colonies of Central Africa, and former French colonies of West and Central Africa) as well as others with national mandates. By then, these institutions had developed considerable technological innovations in the production, processing, and marketing of commercial crops (Carr 1993). Although strong and sustained research and extension capacities are still required to maintain gains, to overcome new technical constraints (e.g., pests and diseases), and to come up with innovations, the most limiting factors are (i) a favorable policy environment and political support, (ii) institutional innovation, and (iii) secure markets, agricultural credit, and reliable supply of inputs. This paper highlights examples of successful adoption of technological innovations in cash crops in Africa as well as instances where available technologies have not been adopted.

Cotton and Associated Crops in Francophone West and Central Africa

The successful generation and diffusion of technology in the cotton zone of francophone West and Central Africa were the result of institutional innovations that addressed several constraints comprehensively and simultaneously. The basic model consists of tightly run programs that encompass the entire cotton subsector: contracts with farmers and extension services, input and credit supply, output marketing including ginning, and technical assistance in companion crops such as maize and sorghum (Bosc and Freud 1994; Jaffee 1992). Institutional responsibility for program management within individual countries lies with national cotton development companies that administer state-supported contract farming. These national

Mohamood A. Noor is Consultant, Special Program for African Agricultural Research, World Bank, Washington D.C.

companies enjoyed long-term association with two French-based institutions operating on regional scales—Compagnie Française du Développement des Fibres Textiles (CFDT), which provided management and technical support as well as an export outlet, and Centre de Coopération Internationale en Recherche Agronomique pour le Développement (formerly Institut de Recherche du Coton et des Textiles Exotiques), which provided linkages with the national agricultural research institutions.

The cotton industry and associated coarse grain crops (maize, and, to a lesser extent, sorghum) saw rapid, extensive development in the countries of francophone West and Central Africa: Benin, Burkina Faso, Côte d'Ivoire, Mali, Senegal, Cameroon, Central African Republic, and Chad. Cotton production, over the entire zone, doubled in the first decade after independence, and has more than tripled over the past 25 years (fig. 1 and table 1). The region's share of world cotton exports increased from 4 percent to 9

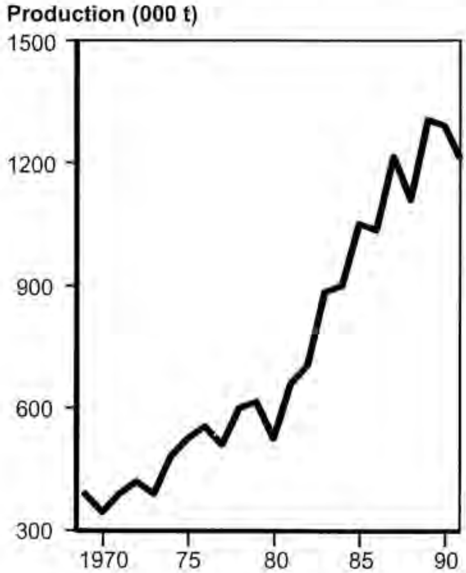

Fig. 1. Seed cotton production in francophone countries (Source: Bosc and Freud 1994).

Table 1. Seed cotton production and yields in West and Central Africa.

	Production (000 t)[a]				Yield (kg/ha)[a]				Fiber extraction rate (%)	
Country	1959–61	1969–71	1984–86[b]	1991–93[c]	1959–61	1969–71	1984–86[b]	1991–93[c]	1961[d]	1988[e]
Francophone countries										
Benin	2	36	103	176	705	844	1,314	1,168	39.3	40.5
Burkina Faso	2	29	124	158	94	368	1,210	894	34.3	40.7
Côte d'Ivoire	4	36	205	226	693	908	1,343	1,083	34.8	44.1
Mali	6	54	168	279	213	753	1,262	1,279	34.8	39.3
Senegal	0	15	34	48	846[f]	1,064	924	1,118	39.5[g]	40.0
Togo	6	4	66	93		730	1,155	1,157	35.7	41.9
Cameroon	25	57	112	122	436	552	1,308	1,249	35.3	41.4
Cent. Afr. Rep.	31	53	35	18	204	404	459	500	36.1	40.7
Chad	82[h]	106	95	132	266[h]	358	691	651	36.8	38.2
Anglophone countries										
Ghana		0	7	21		540	627	1,103		32.0
Nigeria		186	92	271		458	190	624	33	19.6

Sources: FAO production yearbooks (for Ghana and Nigeria) and Ministère de la Coopération 1991, cited in Bosc and Freud 1994.

a\ The calendar years refer to crop seasons beginning in that year (e.g., 1959 is 1959–60 season).
b\ Data for anglophone countries are for 1979–81.
c\ Includes forecast for 1993–94. Data for anglophone countries are for 1990–92.
d\ Data for anglophone countries are for 1969–71.
e\ Data for anglophone countries are for 1990–92.
f\ 1964–66.
g\ 1964.
h\ 1961–63.

percent between 1979/81 and 1992/93 (Bosc and Freud 1994).

The growth in output was associated with impressive productivity gains. Yield increased from under 500 kg/ha to about 1,100 kg/ha in the past 25 years (fig. 2). In some countries, yields reached over 1,300 kg/ha (table 1). These yields compare well with the yields of rainfed cotton worldwide and are well above those in most sub-Saharan African countries. Fiber extraction rates have also increased from 35 percent in the early 1960s to over 40 percent in 1988 (table 1).

Table 2 shows the average rate of growth in yields and export volume. The francophone West African countries that practice contract farming and the associated technological packages have generally better yields and have experienced higher growth in export volume. The countries that used contract farming experienced average increases in export volumes of 7 to 15 percent from 1975 to 1989, while the other countries (except Zimbabwe, which also had favorable market outlets) experienced declines or ceased to export cotton altogether.

The area of maize cultivated in the cotton zone of West and Central African countries increased considerably due to the diffusion of technologies for cotton that were also applicable to maize (Bosc and Freud 1994). In Mali, the area under maize increased from 20,000 hectares in 1980 to over 100,000 hectares by the early 1990s. In Senegal, over the same period, the maize area rose from 6,000 hectares to 18,000 hectares. In northern Cameroon, it grew from 7,000 hectares in 1982 to nearly 35,000 hectares and in the cotton zone in Côte d'Ivoire, it more than doubled from 40,000 hectares to 90,000 hectares.

Technical Innovations

The package of technical innovations for cotton consisted of improved varieties, fertilizer application, appropriate crop calendar (land preparation using animal

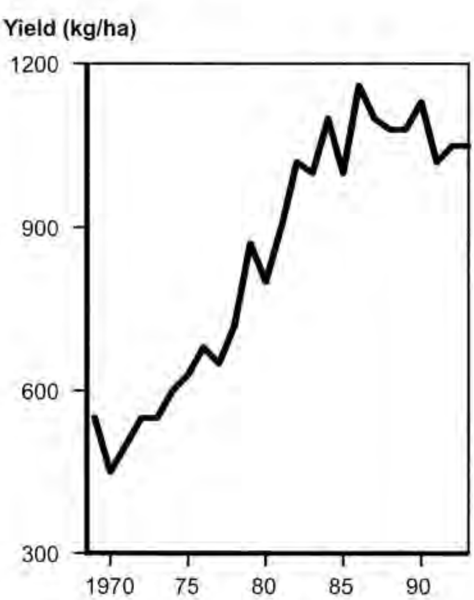

Fig. 2. Seed cotton yields in francophone countries (Source: Bosc and Freud 1994).

Table 2. Cotton industry performance in sub-Saharan Africa, 1975–89.

	Average growth rate (%/yr)	
Country	**Yields**	**Export volume**
Contract farming		
Burkina Faso	3.7	7.3
Cameroon	4.5	14.8
Côte d'Ivoire	5.3	15.7
Mali	0.8	8.9
Senegal	–0.2	8.0
Togo	8.5	14.0
Other systems		
Central African Rep.	5.2	–6.8
Malawi	3.1	–
Nigeria	–3.9	–
Tanzania	–2.2	–0.9
Uganda	na	–5.4
Zimbabwe	–1.7	5.1

Source: Varangis, Akiyama, and Thigpen 1990; World Bank 1992; Jaffee 1992.
– = no longer exporting.
na = not available.

traction, early planting, timely weeding, etc.), insect control, and high fiber extraction rates. Adapted, high-yielding, pest- and disease-tolerant cotton varieties with higher fiber content, length, and quality were released in a continuous stream. In addition, seed production was technically sound and the distribution system was efficient.

Crop husbandry innovations were made in mechanical soil preparation and use of inorganic fertilizers and pesticides. Extensive surveys on the adoption of these practices over time shows that substantial increases in the area under cotton cultivation (with the exception of Central African Republic and Chad) and the percentage of farmers using animal traction, fertilizers, and pesticides (table 3). The introduction of animal traction in land preparation, sowing, and weeding of cotton also had positive implications for associated crops such as maize that benefit from this innovation. In addition, animal-drawn carts facilitated rural transportation, especially between village and field. These innovations, in turn, resulted in the higher yields and increased export volume for cotton.

Although suitable improved varieties of sorghum are not yet available in the cotton zone, several high-yielding and disease-resistant maize varieties were either developed or introduced. In addition, the high rate of adoption of animal traction and a modest rate of adoption of fertilizer have resulted in higher yields for maize (1.5 to 2 t/ha).

Institutional Innovations

The institutional structures created for cotton development were vertically integrated and have left little to chance. They involved technical advice, secure input supply and market, and favorable prices. In return, this arrangement provided the national companies and CFDT with a source of raw material for cost-efficient processing and export (Bosc and Freud 1994). Among the most important features of this contract-farming arrangement were (i) close research-extension-farmer linkages, which facilitated

Table 3. Area under cotton and diffusion of technical innovations in francophone West and Central Africa.

Country	1960–61				1970–71				1988–89			
		Diffusion (%)				Diffusion (%)				Diffusion (%)		
	Area (000 ha)	Animal traction	Fertilizer	Pesticides	Area (000 ha)	Animal traction	Fertilizer	Pesticides	Area (000 ha)	Animal traction	Fertilizer	Pesticides
West African zone												
Benin	–	–	–	–	39	3	68	100	–	–	–	–
Burkina Faso	21	–	–	–	81	13	16	11	170 [a]	37	78	57
Côte d'Ivoire	–	–	–	–	36	4	86	100	213	34	84	100
Mali	34	0	0.5	1.1	66	45	53	70	180	91	88	84
Senegal	0	–	–	–	14	66	100	98	39	60	82	87
Togo	–	–	–	–	4	16	43	76	68 [a]	8	99	99
Central African zone												
Cameroon	64 [b]	7.7	2.3	0.8	102	34	21	3	112	73	93	94
Cent. Afr. Rep.	129 [b]	0	0.8	0.8	126	4	22	40	53	26	38	63
Chad	300 [b]	–	1.2	1.1	302 [c]	37	14	14	199	96	44	44

Source: Ministère de la Coopération 1991.
a\ 1987-88.
b\ 1961-62.
c\ 1971-72.

rapid dissemination of generated technology, and feedback from the field that was closely linked to seeds and input supply, (ii) availability of credit to purchase inputs and animal traction equipment associated with a high rate of credit recovery from cotton proceeds, (iii) guaranteed output market for the farm produce and secure supply for the industry, and (iv) subsidized inputs, but relatively moderate cotton prices.

The system of contract farming is not trouble-free. Fluctuations in international prices of cotton send periodic shocks through the system. The national companies and farmers have responded through (i) reductions in social services, (ii) rationalization of the cost of processing and marketing, (iii) the involvement of farmer associations in the production and cotton collection at village level, (iv) removal of input subsidies, and (v) increase in diversification at farm level. These external dislocations present continuing challenges for the industry.

Tea in Kenya: Sustained Growth

The Kenya tea industry is a major success story. As an earner of foreign exchange, tea exports in Kenya fall second only to tourism (USDA/FAS 1994a). In 1993, Kenya produced a record 211,433 tonnes of tea, exported 188,494 tonnes valued at $318 million, and consumed 23,000 tonnes. This achievement is attributed to (i) higher return on investment, (ii) good physical conditions for tea growing, i.e., rainfed, high altitude areas with a humid climate, (iii) favorable institutional set-up consisting of large-scale tea company estates and smallholders supported by the Kenya Tea Development Authority with input supply, processing, and marketing, and (iv) a sustained flow of technical innovation from the grower-supported Tea Research Foundation of Kenya.

The area under tea increased from 21,448 hectares in 1963 to 100,000 hectares by 1993 with large estates constituting 31,300 hectares and producing 99,374 tonnes and smallholders representing 68,700 hectares and producing 112,059 tonnes (fig. 3). The production of the large estates increased nearly six times in three decades while area expansion only increased 1.7 times indicating that most of the increase came from higher yields (fig. 4). The increase in production from smallholders was from 312 tonnes in 1963 to 112,059 tonnes in 1993 and the area expanded from only 3,527 hectares in 1963 to 68,700 hectares. The large estate and the smallholders contributed 98.3 percent and 1.7 percent of production in 1963, however, in

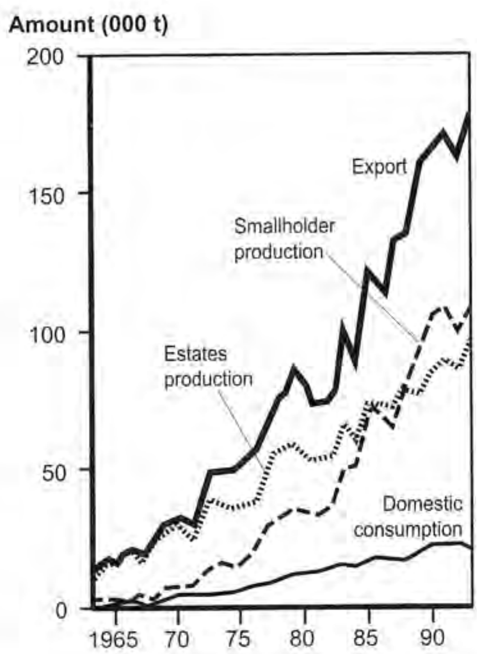

Fig. 3. Kenya's tea production, exports, and consumption, 1963–93; data for smallholders includes estimates for the Nyayo Tea Zones Development Authority (Source: Tea Board of Kenya; Kenya Tea Development Authority).

1993 their respective contribution was 47 percent and 53 percent (table 4). The yield of tea in the large estates increased from 0.9 t/ha in 1963 to 3.2 t/ha in 1993, a 3.3 times increase. For the smallholders, yields increased from 88 kg/ha in 1963 to 1.8 t/ha in 1993, a 20-fold increase (fig. 4). The national average yield, for the same period, increased from 0.8 t/ha to 2.3 t/ha.

Tea is a perennial crop with a productive life of over 100 years (Carr 1993). It requires intensive and careful management with a year-round supply of labor for (i) establishment of vegetative propagation nurseries, (ii) plant establishment, (iii) weed control, (iv) the laying out of contour lines, (v) the shaping of plants to maintain the plucking table, (vi) fertilizer application, and (vii) harvesting and processing.

The selection and the vegetative propagation of superior clones with high quality and productivity is essential to obtain uniform plants with a potential for producing higher yields and quality tea. The techniques for mass vegetative propagation have revolutionized tea production.

The establishment of a crop calls for careful site selection, the establishment of plants along the contour, and adequate soil and moisture conservation measures to avoid soil erosion during early plantation period resulting in the exposure of tea roots. Shaping the plants into a multi-stemmed low-spreading bush about 1 meter tall requires the induction of the plant to produce 4 to 5 young branches from the ground to establish a plucking table of the desired height within 4 to 6 months. Such husbandry tends to result in better establishment and better weed control.

Table 4. Kenya tea production by sector, 1963–93.

		Contribution (%)	
Year	Production (t)	Estates	Smallholders[a]
1963	18,082	98.3	1.7
1968	29,763	88.6	11.4
1973	56,578	73.4	26.6
1978	93,373	62.7	37.3
1983	119,738	57.4	42.6
1988	164,030	47.6	52.4
1993	211,433	47.0	53.0

Source: Tea Board of Kenya; Kenya Tea Development Authority.

a\ Includes output from the Nyayo tea zones.

Horticultural Crops in Kenya

A combination of private initiatives and the facilitating role of the government through the Kenya Horticultural Crops Development Authority have resulted in dramatic growth in horticultural products in Kenya in the past 25 years. The export of fresh and processed fruits, vegetables, and cut flowers have shown a steady growth in volume and value (Jaffee 1992), while some other traditional

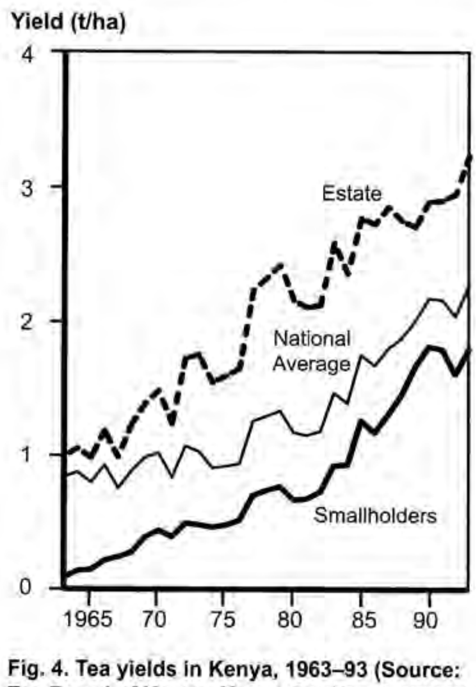

Fig. 4. Tea yields in Kenya, 1963–93 (Source: Tea Board of Kenya; Kenya Tea Development Authority).

exports, such as sisal, pyrethrum, meat products, and cotton, stagnated or declined.

Since the early 1970s, horticultural exports have expanded nearly 12 percent a year, accounting for 16 percent of agricultural export earnings and ranking third after coffee and tea by 1988 (table 5). The growth of horticultural crops is matched only by tea, which has overtaken coffee to become the major export crop.

The most important horticultural crops are canned fruits and vegetables (including canned pineapple and french beans), fruit and vegetable juices (pineapple, passion fruit, orange, and tomato), fresh fruits and vegetables (french beans, chilies, okra, mango, avocado, strawberry, pineapple, and passion fruit), and cut flowers (carnations, roses, alstromeria, chrysanthemums, statice, and orchids). Canned pineapple, pineapple juice, and cut flowers account for 75 percent of the exports. The conditions that led to this healthy growth are:

- The establishment of joint ventures with multinational corporations that often provided the management and the marketing of high-quality produce (e.g., pineapple, french beans, and cut flowers)
- Introduction of contract farming with smallholders (beans) or vertically integrated systems (pineapple)
- The ability to provide off-season fruits, vegetables and cut flowers to Europe
- Availability of air-freight capacities and secure market outlets
- Relatively good infrastructure
- Technical innovation through the introduction and adaptation of production, processing, and packaging technologies

The contribution of official agricultural research and extension into the horticultural sector was limited and belated (Jaffee 1992). However, the National Horticultural Research Station at Thika and the Potato Research Station at Tigoni have carried out useful adaptive research in (i) varietal trials and maintenance of mostly introduced germplasm (potatoes, citrus, avocado, macadamia, and temperate fruit rootstocks), (ii) fertilizer and irrigation requirements of crops, and (iii) disease and pest control for horticultural crops (Dorling 1982). The

Table 5. Commodity shares in Kenya's agricultural exports (% of agricultural export earnings).

Commodity	1914	1935	1955	1964–66	1974–76	1987–88
Coffee	6	37	38	39	39	38
Tea	0	9	12	17	18	30
Horticultural products[a]	0	0	3	3	8	16
Hides and skins	48	7	5	5	4	4
Maize	3	7	7	0	3	4
Sisal	13	17	8	11	7	2
Pyrethrum	0	0	5	6	4	2
Meat, dairy, wool	5	6	4	6	5	0
Oilseeds	18	2	0	1	1	0
Other products[b]	7	14	18	12	11	4

Source: Jaffee 1992. Calculated from data in Department of Agriculture annual reports and Kenyan statistical abstracts.

a\ Including fresh and processed fruits and vegetables and cut flowers.

b\ Including cashew nuts, potatoes, wheat, tobacco, sugar, legumes, cotton, fish products, and wattle bark/extract.

continued growth of the sector will require more involvement of the Kenya Agricultural Research Institute in research in the subsector in partnership with the growers and exporters.

Coffee in Major Producing Countries

The two main commercial coffee types in Africa are derived from Robusta species in the hot, humid lower elevation, and Arabica in the cooler humid highlands. Robusta is the sole source of coffee in Côte d'Ivoire, the leading producer in Africa; Ethiopia and Kenya produce only Arabica. The other major coffee-producing countries grow Robusta in their lower elevations and Arabica in higher elevations (Carr 1993). Table 6 shows the relative importance of the two species in these countries as well as trends in production in recent years and prevailing current yields.

The production of coffee declined or stagnated in the early 1990s but is now beginning to recover as the result of recent favorable markets and improving policy environment in some producing countries. Although Arabica and Robusta are capable of giving on-farm yields of 2 and 3 t/ha, respectively, such yields are seldom achieved as indicated in table 7.

Much research has been carried out in both Arabica and Robusta with the objective of achieving genetic improvement, appropriate cultural practices and ecological conditions, and the control of pests and diseases. As shown in table 7, there are well-tested technologies that could increase the productivity of coffee substantially. There are, however, important disincentives that force farmers to opt for low-input and low-labor systems: (i) the cost of labor, (ii) long-delayed payments for the crop, (iii) the high overhead cost of marketing bodies, (iv) interplanting and competition with other crops, (v) delay in the delivery of inputs (fertilizers and pesticides), and (vi) over-valued currencies.

Technologies for increasing the yield of coffee by smallholders and estates are available. In some countries, these technologies have been applied widely in the past with good results. Their re-adoption will require appropriate measures to reduce marketing and processing costs, timely availability of inputs, elimination of delays in payments to farmers, and more research on removing some of the socio-economic constraints.

Table 6. Coffee production and average yields in major growing countries in Africa.

Country	Coffee grown (%)		Production of green coffee (million bags[a])						Yield
	Robusta	Arabica	1989/90	1990/91	1991/92	1992/93	1993/94	1994/95	(kg/ha)
Côte d'Ivoire	100	–	4.0	3.3	2.1	2.5	2.7	3.2	150
Uganda	87	13	3.2	2.4	1.8	2.5	3.0	3.0	648
Ethiopia	–	100	3.0	3.5	3.6	3.0	3.3	3.4	640
Kenya	–	100	1.7	1.4	1.4	1.2	1.3	1.3	510
Zaire	85	15	1.7	1.7	1.6	1.5	1.5	na	359
Cameroon	80	20	1.4	1.9	1.3	0.8	0.8	1.2	590
Madagascar	90	10	1.2	1.4	1.3	1.3	1.3	na	366
Tanzania	25	75	1.0	0.8	0.9	0.9	0.8	na	200

Sources: USDA/FAS 1993, 1994b;. Carr 1993; FAO 1993, 1994; Machua 1995.
a\ 60-kg bags.

Conclusions

Cash crops in Africa have benefited from technologies that were generated by targeted agricultural research initiated at the turn of the century. The research was global in nature and designed to increase the productivity of tropical commodities that were intended as raw material for industries. Although each colonial power had its own research establishment, there was a significant flow of technology among various systems. Some commodities such as horticultural crops, wheat, and dairy cattle also benefited from the adaptation of technology from temperate zones. Therefore, for cash commodities, technological packages that could result in reasonably high productivity have been available and known to farmers for some time.

The success stories of cotton in West and Central Africa and tea and horticultural crops in Kenya underscores the complementary importance of technological and institutional innovations. On the other hand, the stagnation of coffee in Kenya and the decline of yields in some districts and the loss of its position in export earnings to tea is in part due to reduced capacity to adjust to external shocks and compete. A similar analogy can be made about the competitiveness of cotton in West and Central Africa in general and its decline in other countries in the continent that once were major producers. The availability of technology being equal for most traditional and introduced cash crops, the limiting factors are often rooted in institutional weakness or rigidities that prevent rapid

Table 7. Available technology and constraints to adoption for coffee in Africa.

Available technology	Constraints to adoption	Additional research issues
Robusta (yield potential: 2–3 t/ha)		
High yielding disease and pest tolerant, clonal plant propagation (West Africa, Madagascar, Uganda)	Poor agronomic practices limit potential	Development and transfer of micro-propagation of improved coffee clones Continue genetic improvement
Improved methods of planting, plant population, weed control, mulching, and pruning	Labor cost and inadequate return to labor	Socio-economic studies Labor-saving technology
Use of purchased inputs (mostly fertilizer)	Cost, shading, inadequate cultural practices	Improving technology transfer Studies of organic fertilization
Arabica (yield potential: 2 t\ha)		
Varieties resistant to coffee leaf rust (CLR) and coffee rust disease (CRD) (Ethiopia) Variety (Ruiru 11) (Kenya) resistant to CLR and coffee berry disease (CBD)	Low yields and quality (suitable for low-input production) Production of adequate quantities of planting material	More breeding More breeding and micropropagation Socio-economic studies
Improved method of planting, plant population, weed control and pruning	Labor cost and inadequate return to labor Inadequate extension service	
Use of purchased inputs: Fertilizers where need is determined Spraying for CLR and CBD	Cost	Resistance breeding Integrated pest management

Sources: Carr 1993. CIRAD 1994. Bosc and Freud 1993.

response to competition and in external market instability. Since most of these commodities are derived from perennial species, the abandonment of the recommended technical packages caused by absence of timely and adequate return to investment cannot be compensated for.

The principal limiting institutional issues for most cash crops are (i) over-valued currency, (ii) high overhead cost of government marketing bodies, (iii) inadequate strategies for coping with external shocks, (iv) long-delayed payment of farmers for crops, (v) inefficient and untimely delivery of inputs, (vi) inadequate mutually beneficial arrangements with importing clients, (vii) poor quality control, (viii) the treatment of farmers as passive participants in the production and marketing process, and (ix) lack of research on socio-economic issues and post-harvest technology.

The success stories in this paper point to possible best practices for enhancing the productivity and the competitiveness of cash crops, namely: (i) technological innovation with close research-extension-farmer linkages from production to consumption that facilitate the rapid dissemination and feedback, (ii) timely availability of credit to purchase inputs and sound mechanisms for loan recovery, (iii) guaranteed output market for the producers and secure supply for the industry, (iv) ability to respond to external shocks (e.g., cotton), and (v) adequate infrastructure.

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Integrated Technology Development and Extension with a Long-Term Perspective

Hidero Maki

The effectiveness of having a master program with long-term perspectives for comprehensive development of a sector or a region rather than a project-to-project approach has often been discussed at conferences on official development assistance (ODA) and has been emphasized by international organizations such as UNDP and the Development Assistance Committee of OECD. Hence, JICA (Japan International Cooperation Agency), as an ODA-implementing agency, seeks such programs and integrated approaches where possible. Since 1972 when JICA was founded, its core principle in technical cooperation has been that human resource development will build nations.

In Tanzania, JICA has been involved in the agricultural development of the Kilimanjaro Region for over 20 years. JICA's strategies have been built around integrated technology development and extension aimed at comprehensive regional agricultural development with long-term perspectives and continuous human resource development.

Origin of Japanese Assistance in the Kilimanjaro Region

The Kilimanjaro Region, located in northeastern Tanzania (fig. 1), borders on Kenya to the north and covers an area of 13,000 square kilometers, or 1.49 percent of the nation. The region boasts the grandest peak on the African continent, Mt. Kilimanjaro, standing 5,950 meters above sea level. In the prosperous villages around the foot of the mountain, one senses a bustling energy among the people. These people make up nearly 10 percent of the national population and have made the region one of the strongholds of Tanzania's food production. On the broad skirt of Mt. Kilimanjaro, around the urban center of Moshi, are to be found densely populated lands on which, in the 1970s, primarily coffee and bananas were grown. Through the years, this area has been slowly transformed into a rice-production center for the nation.

In the late 1960s, Tanzania launched a policy of national development emphasizing regional development and decided to shift the authority and responsibility for planning, implementation, and coordination of development programs to each province. In the process of creating its Third 5-Year National Development Plan (1975–80), the Tanzanian government asked the World Bank, European countries, and Japan to draft master plans for comprehensive development programs for 11 major regions.

Japan, as requested, gave its support to drawing up the master plan for the Kilimanjaro Region. Thus in 1973, the Overseas Technical Cooperation Agency (predecessor of JICA) began several surveys and studies in agricultural and industrial

Hidero Maki is Senior Vice President, Japan International Cooperation Agency, Tokyo.

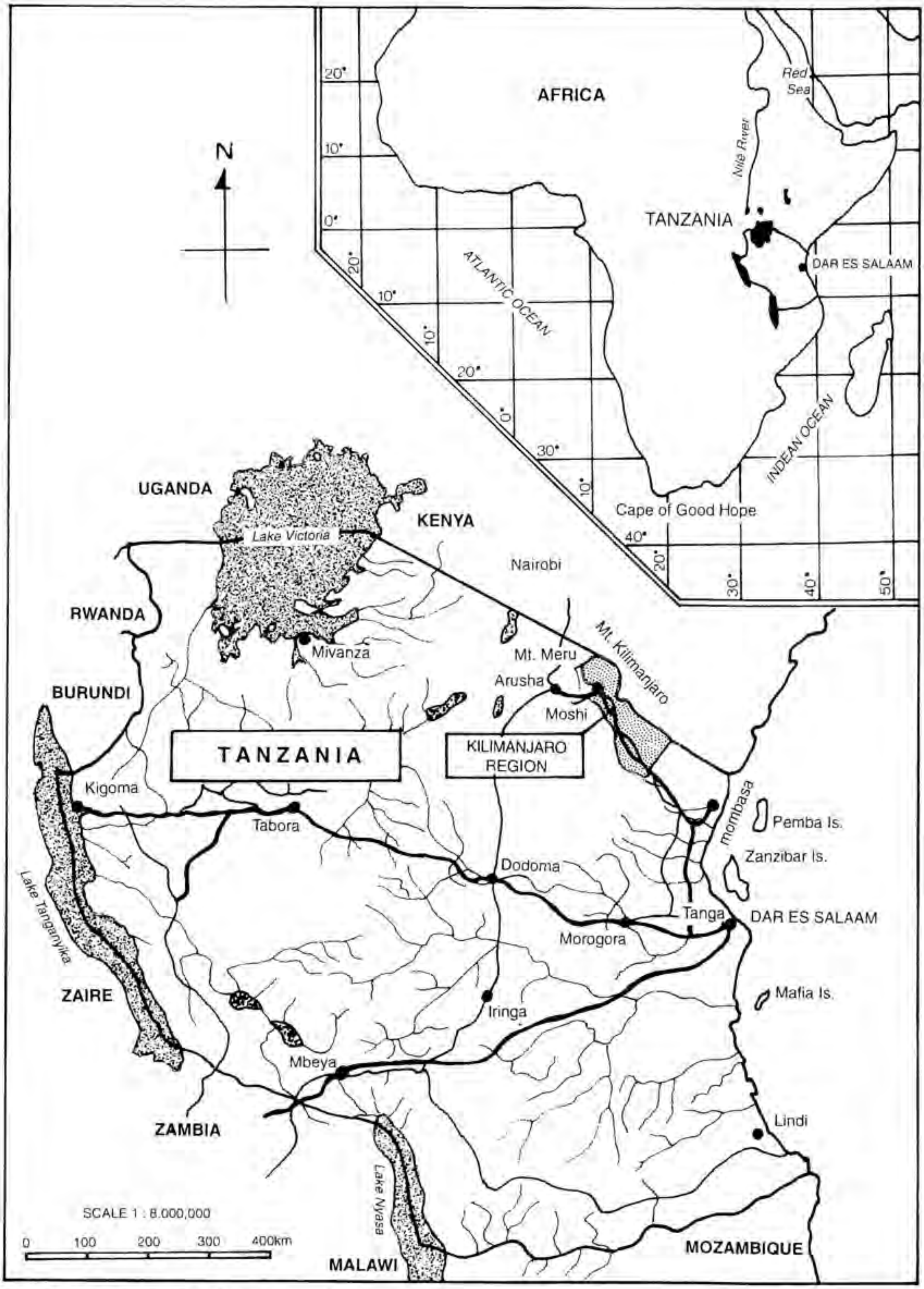

Fig. 1: Kilimanjaro Region, Tanzania

development that were later carried over by JICA. In 1978, JICA completed and submitted the Kilimanjaro Integrated Development Plan to the Tanzanian government. Because the region had limited natural resources and was experiencing food shortages, agricultural development was given the highest priority. The plan stressed agricultural development through self-help based on manpower development and minimum dependence on foreign capital investment. Since then, JICA has been involved in the development of the Kilimanjaro Region, especially in agricultural development.

Japan's official development assistance to the Tanzanian government's proposals based on the Kilimanjaro Integrated Development Plan has been sustained for more than 20 years and is believed to be a significant factor in the region's development.

The major projects that assisted in agricultural development are shown in table 1. These are exclusive of numerous small assistance activities such as individual training programs for Tanzanian officials and technical personnel, the dispatch of Japanese experts for special duties, and provision of machinery and equipment under KRII (grant aid for increased food production).

Aside from agricultural development, Japan has been rendering assistance to the industrial development of the Kilimanjaro region through small-scale industrial development, establishment of the Kilimanjaro Industry Development Center (KIDC), construction of electric power transmission network, and other projects.

Comprehensive Technical Cooperation as the Core of Japanese ODA

JICA's most comprehensive technical cooperation scheme, the *Pro-Gikyo*, has proved an effective tool for assisting relatively large and long-lasting development projects, especially ones involving institution- and capacity-building. A project in this category is carried out with

Table 1. Major projects with Japanese ODA under the Kilimanjaro Region Agricultural Development Program.

Year	Project	Type of assistance
1974–1978	Formation of the Kilimanjaro Integrated Development Plan	Dispatch of experts and study team
1978–1986	*1st Pro-Gikyo:* Kilimanjaro Agricultural Development Center (KADC) Project	Comprehensive technical cooperation
1979–1980	Feasibility study for Lower Moshi Area Agricultural Development Project	Dispatch of study team
1979–1981	Construction of KADC facilities	Grant financial aid
1982–1984	Feasibility study for Mkomazi Valley Area Irrigation Development Project	Dispatch of study team
1982–1987	Execution of Lower Moshi Area Agricultural Development Project (Improvement of 2,300 ha. with irrigation and drainage)	Yen loan
1986–1993	*2nd Pro-Gikyo:* Kilimanjaro Agricultural Development Project	Comprehensive technical cooperation
1987	Improvement of the post-harvest facilities in the Kilimanjaro Region	Grant financial aid
1987–1988	Execution of Ndung Agricultural Development Project, a component of Mkomazi Valley Project (Improvement of 680 ha. with irrigation and drainage)	Grant financial aid
1993–present	Follow-up of the 2nd Pro-Gikyo	Dispatch of experts
1994–present	*3rd Pro-Gikyo:* Kilimanjaro Agricultural Training Center Project	Comprehensive technical cooperation

major technical input from Japanese experts dispatched to the project and with the training of counterpart personnel in Japan. This is accompanied by financial assistance for equipment, the development of facilities such as model and pilot infrastructure (demonstration farms, irrigation facilities, or laboratories), in-country training, and other local activities.

In the case of agricultural development of the Kilimanjaro Region, a series of *Pro-Gikyo* played the core role and coordinated assistance under different schemes such as the master plan and feasibility studies, grant capital aid, and yen loans.[1]

ıstitution Building: Research and Training Center

The first comprehensive technical cooperation undertaking was the Kilimanjaro Agricultural Development Center (KADC) Project in Moshi, Kilimanjaro, carried out from 1978 to 1986. During this period, technical cooperation was also provided for the KIDC Project at the same location.

The project aimed to support the development of the Kilimanjaro Region through the introduction of agricultural techniques and land improvement methods for increasing agricultural productivity. As its major activities, the project conducted experiments to establish appropriate cultivation, irrigation and drainage, and agricultural mechanization.

With the advice and supervision of Japanese experts, feasibility studies for surface water resources were carried out for the Lower Moshi and Mkomazi Valley Irrigation Project. The execution of the project was supported by Japanese government capital assistance, and the Lower Moshi area was covered in later years by phase 2 of JICA's Pro-Gikyo, the comprehensive technical cooperation.

The construction of the KADC was completed with Japanese grant capital assistance in 1981, and 19 hectares of paddy fields and 52 hectares of upland fields were developed as trial farms and pilot farms—some with and some without Japanese financial assistance during the following years.

Tests for the applicability of improved farming techniques were conducted at a trial farm. An effective irrigation system, including water management techniques, crop rotations, etc., was successfully developed for paddy, maize, and beans. Experiments concerned with the selection of appropriate crops, method of fertilizer application, insect and disease control, and seeding time were carried out. Promising crops in the region were found to be maize, sweet potatoes, kidney beans, soybeans, watermelon, and Chinese cabbage.

For maize, which is a staple food in Tanzania, variety and nitrogenous fertilizer application tests found application of urea at 50 kg/ha resulted in significantly increased yield.

Similarly, various experiments were carried out for the development of paddy production; verification trials were conducted with irrigation, transplanting, and mechanized cultivation; and seeds were multiplied for the local variety, improved (mainly IRRI) varieties, and Japanese varieties.

[1] In addition to Pro-Gikyo, coordinated assistance has been provided in various other schemes. For example, under the *Kaihatsu Chosa* (Development Study), a study team is dispatched to carry out master plan studies or feasibility studies.

The Tanzanian researchers have learned experiment design, planning and practice of farm work, data collection, and analysis of experiment results. Some of the proven research findings for upland crops and paddy rice have been demonstrated to farmers through training at a trial farm and a pilot farm. The center also produced some seeds for distribution.

Performance tests on a combine harvester, a harrow for small tractors, and rotary plow for large tractors were mainly carried out in the trial farm. Rice-processing plants were tested in the center and rice milling was improved for the indica-type variety. Consequently, the rate of broken rice was significantly reduced. The Tanzanian counterparts learned both theoretical and practical techniques for the effective use of agricultural machinery, especially tractor attachments.

Extension of improved agricultural techniques including irrigation and drainage, paddy production, upland crops production, and mechanization was a part of the project. Training courses and seminars for the agricultural extension staff, machine operators, and farmer groups were organized and conducted at KADC, the trial farm, the pilot farm, and selected private plots.

Toward the end of the project, human resources were developed and KADC was developed to perform its functions within the development and extension of agricultural technologies suitable for the region.

Extension of the Developed Technologies and Further Capacity-building in Research

Based on the achievements of the first Pro-Gikyo to the KADC Project, which was concluded in 1986, the second Pro-Gikyo-assisted project was begun to further develop agricultural techniques and extend them through training of personnel. The project was thus expected to contribute to the further agricultural development of the Kilimanjaro Region.

The project was carried out from 1986 to 1991 and the activities were mainly concentrated at KADC and in the Lower Moshi area, including 2,300 hectares where irrigation and drainage development under a Japanese loan program of ¥3.3 billion (approximately US$33 million) was completed in 1987.

To achieve its objective, the project was largely implemented in three fields:

1. Further development of the capability of the KADC
2. Capacity-building of the operation and maintenance office of the Lower Moshi Irrigation Project
3. Capacity-building in the agricultural development planning of the project construction and development office

JICA's cooperation inputs to the project included:

- Dispatch of 15 long-term experts in seven technical fields and 6 short-term experts in four fields
- Technical training of 19 Tanzanians in Japan and Egypt
- Provision of machinery and equipment amounting to approximately US$2.5 million
- Other project operating costs amounting to approximately US$820,000, including training courses for technicians, extension workers, and farmers, a technical exchange program with a similar JICA-assisted project in Egypt, and publications
- Dispatch of seven technical advisory and consultation teams

As a result of the project, the following achievements were observed in rice cultivation research:

- Improvement in capability for selecting appropriate paddy varieties for cold tolerance, and the introduction and multiplication of promising varieties. IR54 was identified as an appropriate variety for Lower Moshi.
- Improvement in capability for the establishment of paddy cultivation techniques including suitable planting density, fertilizer application, and weeding. An input package of fertilizers, herbicides, etc., suitable for the Lower Moshi area was developed.
- Minor capability development in verification trials and extension of paddy production.
- Transfer of rice cultivation technology to extension workers and farmers, and improvement in training programs.

Similar achievements were made in research on upland crop production including that of soybeans, tomatoes, cabbage, watermelon, onion, and maize in irrigated conditions, and in agricultural machinery, i.e., continued improvements on the first project. Soil and water management techniques were established and extended during this project phase.

The technical level and capability of the Tanzanian implementing organizations were further improved and extension activities were further strengthened. The major effects at the field level were:

- The average annual paddy production in Lower Moshi rose from 2.5 t/ha to 6.5 t/ha (under double cropping).
- The farming system greatly improved in cultivation technique, cropping pattern, and intensity. A demonstration effect was clearly observed: On 400 hectares, growers upstream learned and applied soil and water management, seeds, and other techniques developed in the project.
- Farmers' incomes have increased in the Lower Moshi area through increased productivity, and consequently the living standard has also improved.
- Through water users associations, the farmers in the area are now organized and maintain tertiary canals.

To follow up the project, Japanese experts in agronomy, agricultural machinery, and soil and water management continue to be dispatched.

Extension Nationwide and More Human Resource Development

Agricultural development based on a long-range master plan over a period of nearly 20 years is now showing its significance. Together with sustained JICA technical cooperation, especially in rice production, the developed production technology now has spread benefits throughout the region. The average paddy yield has reached 6 to 7 t/ha in Lower Moshi, and the farmers are organized and are now even improving water canals with concrete linings at their own expense. Moreover, many upstream farmers of the Lower Moshi and neighboring areas are motivated to engage in rice production and have joined in the reclamation of land for paddy on their own.

Encouraged by the outcomes of the past cooperation in rice cultivation, the Tanzanian and Japanese governments agreed on cooperation for a new nationwide project aimed at extending the technology developed in KADC and tested in Kilimanjaro. Hence, JICA's third Pro-Gikyo commenced in July 1994 and is expected to continue for 5 years.

With respect to irrigated rice cultivation, the purpose of this project is to strengthen the institutional capability for training extension personnel and other concerned people. The training part of KADC facilities has been developed as the Kilimanjaro Agricultural Training Center.

JICA expects this project will:

- enhance the technical capability of trainers
- improve training methods
- improve training materials
- train technical personnel and key farmers in agricultural extension, water management, and agricultural machinery
- improve extension methods and introduce them nationwide

JICA has six long-term experts assigned to the project at present and they have been cooperating to pursue the project along the same lines as the first and second projects. Gender and benefits for the poor have been given more consideration in the third Pro-Gikyo.

Conclusion

It has been shown on a number of occasions that development assistance that operates on a project-to-project basis is often unsatisfactory in its long-term outcomes, and that a comprehensive long-term cooperation is often more effective, particularly in areas of economic and political instability. A project-to-project approach may encounter problems derived from external factors, such as unpredictable political changes, unforeseen economic mismatches, and so on, that halt progress and that prevent assistance from the original cooperation partner.

With regard to the Kilimanjaro Region, a comprehensive regional agriculture development approach proved to be particularly efficient and beneficial for the area. As capabilities increased and institutions developed, JICA was on hand to add techniques, machinery, and so on to expand the project's scope. It should be remembered, however, that comprehensive regional development can only achieve maximum results in coordination with a national development policy and long-term development strategies and also that capital assistance goes hand in hand with technical assistance to make project truly successful. Fortunately, the Kilimanjaro Region and JICA planned and followed such an approach and thereby achieved remarkable results.

Human resources are a country's treasure and the engine for nation-building. Since the Kilimanjaro Region has limited natural resources, planning for the project saw human resources as the nation's natural resource and stressed the need for agricultural development to hold a self-help principle.

Along with minimum dependence on foreign capital investment, the Tanzanians, assisted by JICA, have proved that growth and development derived from sound planning and coordination are possible.

Survey of Agricultural Research Investments in sub-Saharan Africa

Johannes Roseboom and Philip G. Pardey

There is a perception the world over that public agricultural research systems need to be revamped and revitalized. This perception is particularly prevalent in regard to African agricultural research systems. After significant increases in investments in public-sector agricultural research throughout much of Africa in the 1960s and 1970s, the 1980s saw a reversal of this trend. Growing levels of international indebtedness and programs of structural adjustment spurred government austerity programs that curtailed public-sector spending in general and scaled down public investments in agricultural research. Bilateral and multilateral grants and loans made up for some of the shortfall although many national systems experienced stagnant or declining amounts of real support over recent years. [1]

Consequently, renewed attention is being paid to the policy options for public agricultural research in Africa and elsewhere. To think through these options in a meaningful way requires a good grasp of the current agricultural research situation in Africa and some understanding of the history behind the present policies and institutional arrangements. In this paper we use an entirely new data set to quantitatively review patterns of investments in African agricultural research as a basis for evaluating the policy options for agricultural research in the region. In presenting and commenting on investments in public research, we note the growing awareness that simply seeking more dollars is not the answer. The financing, organization, and management of public research will have to be dealt with in an integrated way (Alston and Pardey 1996).

Institutional Developments

A Brief History

With political independence in the late 1950s and early 1960s, most African countries inherited agricultural research structures that operated as part of a regional system. As the old colonial structures collapsed, many smaller countries found themselves effectively cut off from the network of research services to which they previously had had direct access. Other countries were left with highly specialized research agencies that did not necessarily address local production problems. There were major incongruencies among countries in research capacity. Moreover, research was largely oriented to meeting the demands of export agriculture and gave little attention to the production constraints faced by subsistence farmers.

1 Accounts of the development of African agricultural R&D can be found in Lipton 1988, Lele, Kinsey, and Obeya 1989, Eicher 1990, Pardey, Roseboom, and Anderson 1991, Anderson, Pardey, and Roseboom 1994, and Pardey, Roseboom, and Beintema 1995.

Johannes Roseboom is an Officer, International Service for National Agricultural Research, The Hague, and **Philip Pardey** is a Research Fellow with the International Food Policy Research Institute, Washington D.C.

In the post-independence period, the former British and French colonies followed different paths (see Eisemon, Davis, and Rathgeber 1985). Throughout much of anglophone Africa, the local agricultural research infrastructure and administrative control was ceded to the new governments as an integral part of their administrative structures. In many cases, the flow of financial and technical support for research from Great Britain to its former colonies contracted quickly, leaving the responsibility for financing and managing research facilities fully vested with the new governments.

In contrast, France continued to manage, execute, and fund agricultural research in most of its former colonies for many years following political independence. Research costs were shared by France and the host governments under a series of bilateral agreements. In most instances, France continued to provide scientists and cover related costs while the host country provided support staff. Eventually these arrangements collapsed as African governments sought complete managerial and financial control over the research agencies operating within their borders.

As a consequence of these developments, the Africanization of agricultural research occurred more slowly in francophone Africa than in anglophone Africa. In 1991, for example, 21 percent of the researchers working in francophone Africa were expatriates compared with 7 percent in anglophone Africa. [2] Moreover, the indigenous capacity to train students in the agricultural sciences is still much more limited in francophone Africa than in anglophone Africa.

Size

During the past three decades African national agricultural research systems have grown substantially.[3] In particular, the number of mid-sized systems (those employing 100 to 400 researchers) increased. In 1961 there were only 3 such systems, but by 1991 there were 18 (fig. 1). Similarly, only eight national agricultural research systems in Africa currently employ less than 25 full-time-equivalent researchers compared with 33 systems three decades ago.

Despite the general expansion, several research systems have collapsed or contracted sharply since independence because of political instability and civil war. Examples are Zaire, Angola, Mozambique, Uganda, and, more recently, Liberia, Somalia, and Rwanda.

Structure

Public-sector agricultural research in Africa is done mainly by government agencies.

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2 The data summarized in this paper are reported in a series of country statistical briefs prepared by ISNAR (available on request). The briefs were compiled on the basis of information obtained in a detailed survey of national agricultural research agencies and, where necessary and appropriate, from secondary sources. The data were collected and compiled using international standards laid down in the Frascati manual for developing science indicators (OECD 1981).

3 The concept of a national agricultural research system used in this study covers all research focusing on crop, livestock, forestry, and fisheries production issues. The institutional coverage comprises government, semi-public, and academic research agencies operating at the national level. Because of data constraints, supra-national and private-for-profit research agencies are not included.

Semi-public agencies[4] and universities play only a minor role (table 1).

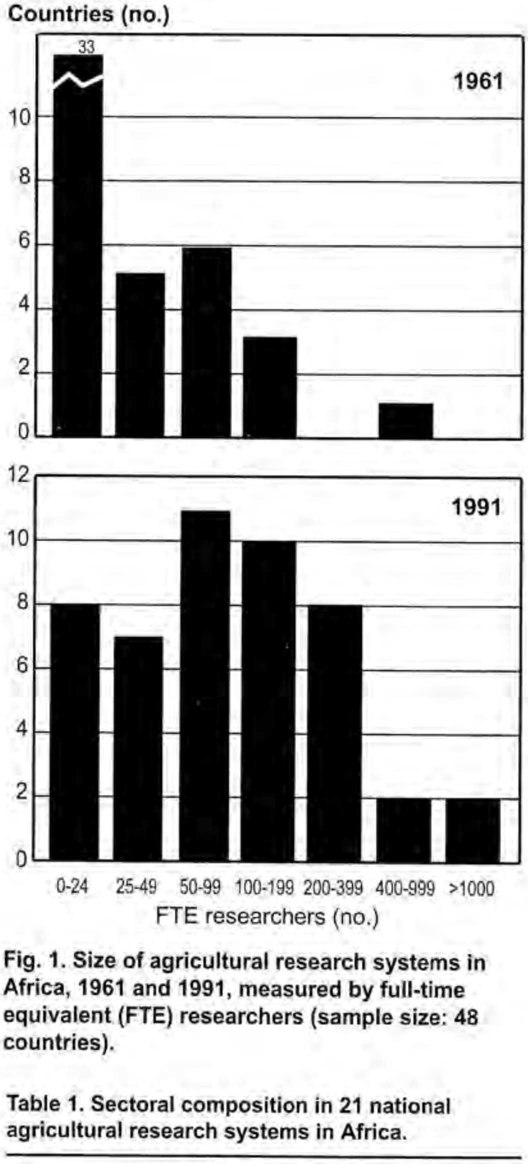

Fig. 1. Size of agricultural research systems in Africa, 1961 and 1991, measured by full-time equivalent (FTE) researchers (sample size: 48 countries).

Table 1. Sectoral composition in 21 national agricultural research systems in Africa.

Category	Full-time-equivalent researchers (%) 1961	1971	1981	1991	Growth[a] (%) 1961–91
Government	90.7	89.1	89.0	86.5	5.0
Semi-public	4.2	3.8	3.1	3.5	3.6
Academic	5.1	7.1	7.9	10.0	7.1
Total	100	100	100	100	5.1

a\ Annual average growth rates calculated using a least squares regression method.

Government research agencies are those directly or indirectly administered by government, which in practice often means the research departments of ministries of agriculture or agricultural research institutes directly under a ministry. In contrast, semi-public agencies are not directly controlled by government and have significant autonomous sources of funding, usually a compulsory cess or marketing-board profits. They usually provide research services for a particular, and often economically significant, export commodity. Examples include agencies doing research on coffee (Kenya), sugar (Mauritius and South Africa), tea (Kenya and Malawi), and tobacco (Zimbabwe).

All the semi-public research institutes covered in this study were in former British colonies and virtually all were established during colonial times. In the former French colonies, commodity boards often play an important role in technology adoption by providing farmers with standard packages of inputs. The boards, however, do not have research facilities. In the past they relied on the French-managed commodity research institutes for new technology and, since these institutes were taken over by national governments, they have relied on the national agricultural research entities that replaced

[4] Semi-public research agencies constitute agencies that are not directly controlled by government and that have no explicit profit-making objective. Thus before classifying an agency as semi-public, we required that it be governed by an autonomous board and also exhibit a certain degree of financial independence from the government. As a practical matter, we required that an autonomously governed agency receive more than 25% of its income from sources other than government and international donors before classifying it as semi-public.

them. To our knowledge, commodity boards in former French colonies do occasionally fund some of the research conducted by the government research agencies, but we found no case where this was more than 25 percent of the budget of a particular research agency. Because few semi-public agencies have been established since 1961, they make up a declining share of the human resources going to agricultural research (4.2% of the research staff in 1961 against 3.5% in 1991).

University-based agricultural research has expanded markedly. The number of full-time-equivalent researchers at universities grew on average by 7.1 percent per annum during the past three decades and 10 percent per annum if South Africa is excluded. In 1961 only a few countries had the capacity to provide training in the agricultural sciences to the B.Sc. level. Now, almost all African countries have some. Considerably fewer countries, however, can provide postgraduate training.

Despite the rapid growth in university-based agricultural research in Africa, this sector still accounts for only 10 percent of the overall full-time-equivalent agricultural researchers in the region. Initially, university faculty throughout post-independence Africa were almost fully occupied educating graduates to staff the emerging national bureaucracies. Although the time they spent doing research has grown gradually over the years, most faculty still dedicate less than 20 percent of their time to this endeavor. Further, the research they do is mainly discipline-based rather than applied research aimed at solving specific production problems of farmers. Nevertheless, university personnel represent the better qualified component of most national agricultural research systems. The challenge is to usefully mobilize and manage this highly fragmented potential without undermining (and instead, it is hoped, enhancing) their important role in training the next generation of African researchers.

Research Personnel

Many African countries have significantly increased the number of scientists working in their agricultural research agencies. In 1961 there were about 2,000 full-time-equivalent researchers working in sub-Saharan Africa (including South Africa). By 1991 there were more than 9,000.[5] For 19 countries, accounting for about 68 percent of the region's researchers, more complete time-series data are available (table 2). Building from a rather small base that was initially made even smaller by the exodus of expatriate scientists in the years immediately following independence, the annual average growth in numbers of scientists was 6.2 percent through the 1960s, 4.8 percent in the 1970s, and only 2.8 percent in the 1980s. But the totals mask a good deal of cross-country variation. During the 1980s, agricultural research staff in Ethiopia, Madagascar, and Rwanda grew 8 to 10 percent per annum, while the number of scientists working in Botswana, Nigeria, and Senegal failed to increase.

Expatriate Researchers

The composition of the scientific workforce has also undergone substantial change. Expatriates account for only 11 percent of the researchers currently working in national agencies throughout sub-Saharan Africa

[5] This total encompasses 48 sub-Saharan African national agricultural research systems. For 11 (usually small) national systems, an informed estimate, often involving extrapolations from secondary data or semi-processed but incomplete survey data, was used in constructing the 1961 and 1991 regional totals. These data exclude personnel working at or for international or regional agencies.

(excluding South Africa), down dramatically from about 90 percent in the early 1960s. However, the proportion varies widely among countries. In 1991 more than a quarter of the agricultural scientists working in Botswana, Cape Verde, Central African Republic, Côte d'Ivoire, Mozambique, Rwanda, Senegal, and the Seychelles were expatriates. In Nigeria, Mauritius, South Africa, Sudan, and Tanzania, they constituted less than 5 percent of the total. Former French colonies typically employ a higher proportion of expatriate researchers than former British colonies, reflecting the comparatively slower transition to full national control of local agricultural research facilities in francophone countries.

Degree Status

Not only has the number of agricultural researchers in Africa increased fourfold since 1961 (sixfold if South Africa is excluded), but the levels of formal training have improved as well. Nearly 65 percent of the national researchers in countries included in figure 2 have postgraduate degrees compared with 45 percent just a decade earlier. An estimated 1,372 of these researchers, or about 22 percent, hold a Ph.D., although 63 percent of them work in just three national agricultural research systems—those of Nigeria, South Africa, and Sudan. Indeed, 52 percent of the researchers working in Sudan hold a Ph.D., which is an exceptionally high proportion compared with most other countries.

Research Expenditures

Real agricultural research expenditures grew rapidly during the 1960s, moderately during the 1970s, and not at all in the 1980s and early 1990s for the 19-country sample

Table 2. Full-time-equivalent (FTE) researchers working in 19 African national agricultural research systems.

	FTE researchers[a] (no.)				Annual growth rate[b] (%)			
Country	1961	1971	1981	1991	1961–71	1971–81	1981–91	1961–91
Botswana	1	16	47	54	31.9	11.1	–0.2	12.5
Burkina Faso	10	25	91	142	11.3	12.3	2.8	9.8
Côte d'Ivoire	67	135	192	267	6.4	3.9	3.7	4.2
Ethiopia	14	66	153	387	17.1	7.3	9.6	11.0
Ghana	57	132	180	278	9.6	2.8	4.4	4.2
Kenya	121	326	484	819	10.5	3.0	4.8	6.4
Lesotho	1	7	17	28	19.2	8.3	5.2	10.4
Madagascar	70	114	95	195	5.2	–2.7	8.6	2.2
Malawi	30	81	126	185	12.0	4.8	3.2	6.1
Mauritius	12	39	73	106	12.9	5.7	3.8	7.3
Niger	12	14	50	102	1.0	17.6	6.6	9.3
Nigeria	136	364	944	1,013	10.4	10.8	–0.3	7.5
Rwanda	5	16	28	57	9.0	7.0	9.5	8.8
Senegal	60	71	184	175	2.2	11.5	–1.1	5.4
South Africa	737	957	1,140	1,339	2.7	1.6	1.3	2.0
Sudan	48	125	324	424	9.4	8.6	2.3	8.4
Swaziland	6	12	5	20	5.7	–9.8	5.6	3.8
Zambia	26	101	175	279	14.4	4.6	4.1	8.0
Zimbabwe	114	167	173	291	3.4	–0.5	5.9	2.7
Total	1,525	2,769	4,481	6,159	6.2	4.8	2.8	4.9

a\ Crop, livestock, forestry, and fisheries researchers working in government, semi-public, and academic agencies.
b\ Growth rates were calculated using a least squares regression method. Hence, the rates may differ from those obtained using only the end points.

reported in table 3. But the more detailed data reveal substantial volatility and cross-country variation around this trend. Long-term growth rates ranged from 13.2 percent per annum for Botswana to –2.4 percent for Madagascar. The pattern of growth in Nigeria's agricultural research expenditures is noteworthy. After substantial increases during the 1960s and 1970s, largely financed by revenues from a booming oil sector, Nigeria's agricultural research expenditures contracted sharply during the 1980s. Total expenditures are currently less than half what they were in the late 1970s.

Resources per Researcher

The pattern of growth of real research expenditures contrasts starkly with that of research personnel. From 1961 to 1981, the number of research personnel and the amount of resources committed to research developed largely in parallel but thereafter followed dramatically different paths (fig. 3a). Real expenditures stalled after 1981 while the number of researchers continued to climb. As a result, the amount of resources per researcher in 1991 for this group of 19 countries averaged about 66 percent of the amount allocated in 1961. Only Botswana, South Africa, Swaziland, and Zimbabwe committed more resources per scientist in 1991 than they did three decades earlier.

The national research systems in South Africa and Nigeria—two countries that together accounted for 37 percent of the region's total investment in agricultural research and development in 1991—developed in distinctively different ways during the past 30 years (fig. 3c and 3d). The South African system grew slowly but steadily, and the rate of growth of its real research expenditures kept pace with the growth of its research staff.

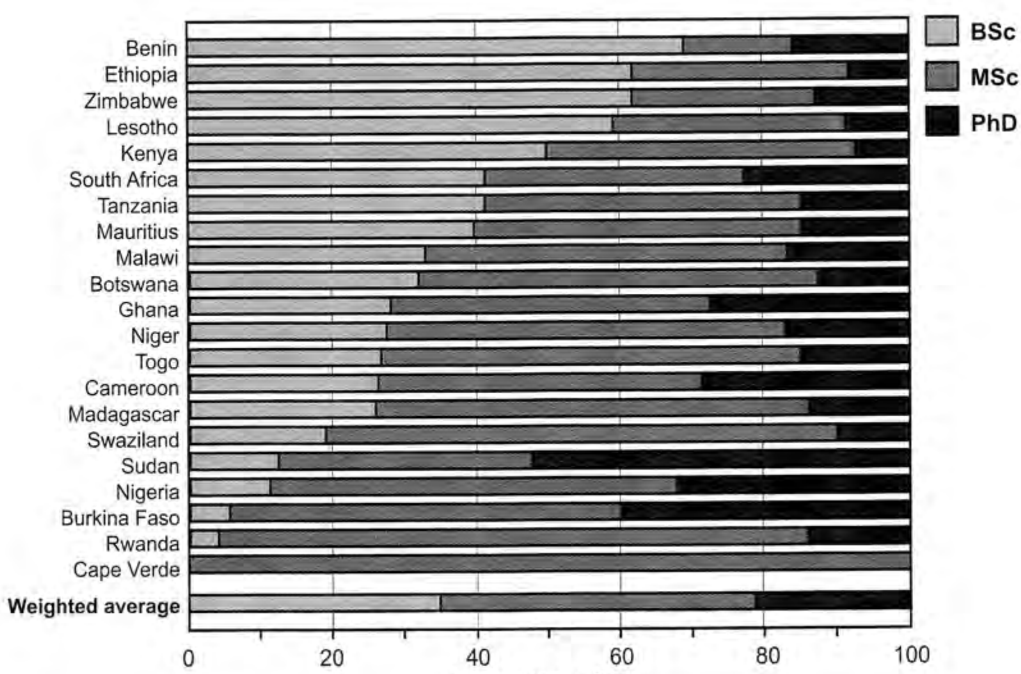

Fig. 2. Degree level of national researchers in 21 African countries, 1991.

In contrast, the Nigerian system had an erratic pattern of development. Fueled by a boom in public revenues from oil exports, research spending and staff numbers grew rapidly during the 1960s and 1970s. But during the 1980s, research spending declined dramatically while the number of research staff stayed constant. The drop in research spending not only coincided with the rapid contraction of overall government revenues but also reflected a shift in government priorities away from agricultural research. Public spending on agricultural research accounted for 0.84 percent of consolidated government expenditures in 1981 but a mere 0.27 percent in 1991. The earlier rapid growth in the Nigerian national agricultural research system was characteristic of national agricultural research systems throughout the region at that time. Many African countries pursued policies that led to a rapid growth in their national agricultural research systems, though often from a small base.

Excluding the Nigerian and South African systems changes the quantitative but not the

Table 3. Agricultural research expenditures by 19 African national agricultural research systems.

	Total agricultural research expenditures [a] (million 1985 PPP dollars)				Annual growth rate[b] (%)			
Country	1961	1971	1981	1991	1961–71	1971–81	1981–91	1961–91
Botswana	0.18	2.67	10.84	9.82	30.3	13.8	–3.8	13.2
Burkina Faso	1.61	2.85	7.11	19.13	7.9	9.3	9.5	8.1
Côte d'Ivoire	18.04	34.69	39.39	37.61	5.5	1.1	0.1	1.8
Ethiopia	1.90	9.19	21.14	40.53	19.4	7.7	10.6	10.4
Ghana	12.15	17.92	13.54	32.52	4.8	–3.2	14.4	2.1
Kenya	22.36	49.69	62.28	95.97	8.4	1.7	4.0	4.4
Lesotho	0.25	1.85	3.78	3.60	20.6	6.6	–1.8	8.1
Madagascar	17.89	29.28	11.45	15.63	4.7	–7.4	3.0	–2.4
Malawi	8.11	17.36	21.95	27.31	9.9	2.4	2.4	4.0
Mauritius	3.20	7.59	9.63	12.63	9.1	1.8	1.3	4.0
Niger	1.99	4.31	8.04	9.83	8.2	12.6	3.9	6.7
Nigeria	42.15	92.07	211.86	86.90	6.4	7.1	–9.1	1.9
Rwanda	1.97	3.63	5.77	10.03	5.8	6.7	11.4	5.7
Senegal	17.82	25.48	37.36	23.85	2.9	4.7	–4.3	2.7
South Africa	74.91	140.47	140.17	163.93	6.0	–0.6	1.8	2.0
Sudan	12.99	34.94	39.90	21.46	9.9	0.5	–5.5	1.5
Swaziland	1.05	2.87	3.53	5.89	8.4	–1.2	–2.4	6.6
Zambia	4.18	14.81	19.66	24.67	14.3	4.0	0.0	5.3
Zimbabwe	13.61	26.43	33.65	43.25	6.3	1.1	4.2	3.6
Total	256.37	518.10	701.03	684.55	6.8	2.6	0.1	2.9

a\ Expenditures include all salary, operating, and capital costs irrespective of the source of funding. The (international) salaries of expatriate researchers paid directly by donors have been included. To secure an internationally comparable measure of the real resources used for research, the expenditures in local currency units were first deflated to base year 1985 with a local GDP deflator (World Bank multiple years) and then converted to 1985 PPP dollars using 1985 purchasing power parities (PPPs). PPPs are synthetic exchange rates that attempt to reflect the purchasing power of different currencies. The PPP indexes used here are derived from the UN International Comparisons Program and published by Summers and Heston (1991) as the Penn World Table (Mark 5). Using market exchange rates to convert local currencies to U.S. dollar-denominated spending aggregates gives a 19-country 1991 total of an estimated $305 million in 1985 US dollars.

b\ Growth rates calculated using a least squares regression method.

qualitative picture of spending per scientist (fig. 3b). From 1961 to 1991, the number of research personnel climbs steadily in both figures 3a and 3b. For the 19-country group, however, real research spending ceased growing after 1981, while for the 17-country group, it continued to grow throughout the whole period, albeit much more slowly after 1971 than in the 1960s. Thus excluding Nigeria and South Africa from the sample dampens the rate of decline in overall spending per scientist compared with the rate for the 19-country sample, but the decline begins much earlier. As a consequence, for the 17-country sample, spending per scientist by 1991 is about 53 percent of the level three decades earlier.

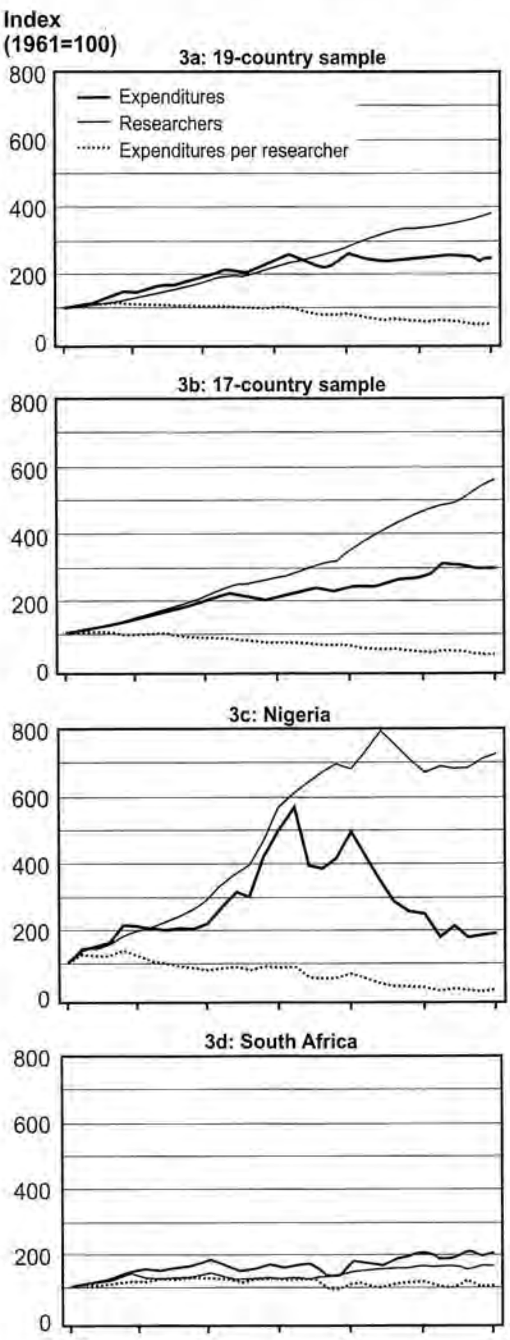

Fig. 3. Growth in research expenditures, staff, and spending per scientist (17-country sample excludes South Africa and Nigeria).

Government and semi-public agencies developed in very different ways. Since the large majority of the researchers work in government agencies, the country aggregates are driven mainly by developments in those agencies. Figure 4 shows ratios of spending per scientist for eight major semi-public institutes in five countries, which employed 236 researchers and spent $50.4 million (1985 PPP[6]) in 1991. For these agencies, the growth in real expenditures slightly exceeded the growth in personnel. Their spending-per-scientist ratio in 1991 was 12 percent higher than in 1961, as compared with the 36-percent lower spending-per-scientist ratio for the government agencies in 19 African countries (fig 3a).

Cost Structures

The spending-per-scientist patterns shown in figures 3 and 4 reflect several factors. Aside from the obvious asymmetries between the growth in total spending and the growth in the number of scientists supported by those expenditures, there are dramatic differences

[6] See note *a* in Table 3.

across agencies and changes over time in the composition of these personnel and expenditure aggregates.

There were several partially offsetting developments in the researcher aggregates. First there was a widespread move to replace relatively expensive expatriate scientists with less costly national researchers. Working in the opposite direction was the considerable upgrading of the degree status of local scientists. The training and additional salary costs implied by these developments are substantial. Another aspect that affects estimates of spending per scientist is the size and composition of the support staff. Although some research agencies have shed excess support staff in recent years, this tendency has been far from universal. Overstaffing with support personnel is still a problem for many government research agencies. In addition, changes in the mix of support staff—for example, semi-skilled versus trained technical staff—are also relevant in this regard.

Related issues are reflected in the cost structures that underlie the expenditure aggregates. Systems that had major programs of capital investments are likely to have

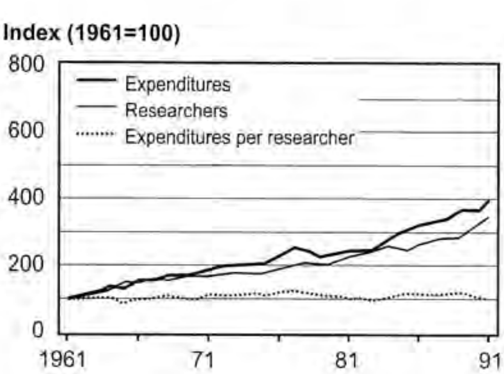

Fig. 4. Growth in research expenditures, staff, and spending per scientist by semi-public agencies in five countries.

higher spending-per-scientist ratios than those that simply maintained existing physical infrastructure. Although no comprehensive cost-share data for the years prior to 1986 are available, fairly adequate data do exist for the later years. These data suggest that overall cost *shares* were reasonably stable throughout this period, although real spending per scientist, at least in the aggregate, continued to decline (table 4).

The stability in these overall cost shares belies dramatic inter-institutional differences in the underlying cost structures. Table 4 also reports the cost components for government and semi-public agencies on a per-researcher basis. The amount of real resources per scientist in the semi-public agencies is nearly twice that of the government agencies, and this difference persists across the personnel, operating, and capital cost components. This points to significant, and possibly very important, differences in the way government and semi-public agencies allocate their research budgets.

Anecdotal information suggests that research throughout Africa is severely curtailed because of inadequate operational resources. The quantitative evidence in table 4 seems to contradict this view, particularly for the semi-public institutes. But, it may be that a disproportionate share of operational funds are consumed by burdensome administrative overhead and the maintenance and upkeep of an extensive network of (comparatively small) research stations and farms. This seems especially so for government agencies. These funds might never find their way into bench-level research. For the semi-public agencies, the relatively high operational costs per researcher may partly arise because these agencies commonly earn much of their income from estate farm operations that employ significant numbers of field staff. Disentangling farm costs from research-related costs is difficult.

The evidence in table 4 clearly points to the salary crunch that has bedeviled scientists working in government agencies. Researchers' salaries are constrained by civil service regulations, which often do not adequately reflect the differences between conducting research and providing other government services. For many African countries, the purchasing power of civil servants deteriorated dramatically during the past two decades because governments only partially compensated for inflation.[7] The result has been widespread absenteeism in many research agencies as staff work at other, additional jobs. Research managers face a dilemma in dealing with this problem. Freeing resources by reducing staff is often made difficult by public-service regulations. The same regulations also make it difficult to raise the salaries of scientists beyond the public-service salary structure.

Funding Agricultural Research

The common claim is that market failures in agricultural research and development lead to underinvestment in research if left to the private sector; research opportunities that would be socially profitable go unexploited. These market failures arise because some research is privately unprofitable due to "appropriability" problems—that is, the innovator (or investor) cannot appropriate all

7 Robinson (1990) provides ample evidence of the declines in real pay of civil servants in 22 African countries. He also notes a tendency to compress the salary scale by increasing the lower salaries faster than the higher ones, which has adverse effects on the motivation and efficiency of the higher grades (possibly causing the most able to resign).

Table 4. Cost components for research in 17 African countries[a].

Cost category	Expenditures per researcher[b] (thousands of 1985 PPP dollars)						Cost shares (%)					
	1986	1987	1988	1989	1990	1991	1986	1987	1988	1989	1990	1991
					Government agencies							
Personnel	74	68	71	72	67	67	59.3	56.0	57.1	59.1	60.3	61.2
Operating	35	32	33	32	30	27	27.7	26.2	26.5	26.1	26.7	24.9
Capital	16	22	20	18	14	15	13.0	17.7	16.3	14.9	13.0	14.0
Total	125	122	124	121	111	109	100	100	100	100	100	100
					Semi-public agencies							
Personnel	130	111	119	118	104	103	52.2	49.6	51.0	46.3	47.1	50.4
Operating	83	76	76	82	77	72	33.3	34.1	32.5	32.1	34.9	35.0
Capital	36	36	38	55	40	30	14.4	16.2	16.4	21.6	18.0	14.6
Total	249	224	233	255	221	204	100	100	100	100	100	100
					Government and semi-public agencies							
Personnel	76	70	73	73	68	68	58.8	55.6	56.7	58.1	59.3	60.4
Operating	36	34	34	33	31	29	28.1	26.7	26.9	26.5	27.3	25.6
Capital	17	22	21	19	15	16	13.1	17.6	16.3	15.4	13.4	14.0
Total	130	125	128	126	115	113	100	100	100	100	100	100

a\ Burkina Faso, Cape Verde, Côte d'Ivoire, Ethiopia, Ghana, Kenya, Madagascar, Malawi, Mali, Mauritius, Niger, Nigeria, Rwanda, Senegal, South Africa, Togo, and Zimbabwe.
b\ Salaries and benefits received by both national and expatriate researchers plus the personnel costs of all technical, administrative, and other support staff scaled by the number of full-time-equivalent researchers. See note a, table 3, for explanation of PPP dollars.

the benefits—or the transaction costs involved in having farmers take collective action to finance (or execute) research that is beyond their individual reach are too high. Alston and Pardey (1996) give a comprehensive and critical review of the evidence on market failures in agricultural research and discuss the principles and practices involved in designing ideal arrangements to *finance* or *conduct* research.[8]

One principle Alston and Pardey (1996) propose for solving the underinvestment problem is that the solutions or arrangements one may recommend depend on which type of market failure is present. Thus developing a detailed understanding of the existing pattern of investments and the institutional context within which research funds are raised, allocated, and spent is an invaluable first step in designing appropriate policy interventions to deal with the problem.

Institutional Differences

Table 5 presents data on the financing arrangements for agricultural research in 13 countries. There are substantial differences in the sources of support for government versus semi-public agencies. While government agencies developed in ways that are broadly consistent with the aggregate country data, semi-public agencies receive about 80 to 90 percent of their funds from earmarked taxes and their own income. Moreover, since the mid-1980s, the share of funds for semi-public agencies coming from general taxpayer revenues diminished while donor-sourced funds being channeled to these agencies increased noticeably.

[8] See also Thirtle and Echeverria (1994) who discuss some of the roles of public and private agricultural research agencies in sub-Saharan Africa.

Donor Funding

Funding in the form of loans and grants from international donors accounted for around 34 percent of total research expenditures in Africa (excluding South Africa) during the early 1980s (Pardey, Roseboom, and Anderson 1991). As a group, African national agricultural research systems have increasingly relied on donor-sourced funds in recent years. Donor funding increased to about 43 percent in 1991 (table 5). Whether this reflects a temporary trend to shore up cash-strapped government research systems in African countries that continue to carry extraordinarily high levels of foreign debt or a crowding out of alternative, local sources of finance is unclear. Analogous arguments were made by Alston and Pardey (1995)

Table 5. Funding sources for agricultural research in 13 African countries,[a] 1986–91.

	Share of funds (%)					
Source	1986	1987	1988	1989	1990	1991
Government research agencies						
Government	57.9	51.5	52.6	51.1	51.4	49.9
Own income	5.3	5.4	6.1	5.5	4.5	4.2
Taxes	0.0	0.0	0.0	0.0	0.0	0.0
Donor	35.5	41.7	39.8	42.5	43.1	45.1
Other	1.3	1.3	1.4	0.9	1.0	0.7
Total	100	100	100	100	100	100
Semi-public research agencies						
Government	11.3	8.5	6.2	7.4	5.8	4.4
Own income	32.1	15.0	17.6	11.3	17.8	17.6
Taxes	50.0	66.6	65.3	59.5	69.1	69.6
Donor	3.9	8.3	9.7	19.4	5.8	7.3
Other	2.8	1.5	1.3	2.4	1.6	1.1
Total	100	100	100	100	100	100
Government and semi-public research agencies						
Government	55.9	49.6	50.4	49.0	49.0	47.5
Own income	6.5	5.8	6.7	5.8	5.1	4.9
Taxes	2.3	3.5	3.6	3.9	4.0	4.2
Donor	34.0	39.7	37.9	40.3	40.9	42.7
Other	1.4	1.4	1.4	0.9	1.0	0.8
Total	100	100	100	100	100	100

a\ Burkina Faso, Côte d'Ivoire, Ghana, Kenya, Madagascar, Malawi, Mali, Niger, Nigeria, Rwanda, Senegal, Zambia, and Zimbabwe.

about the displacement of private sources of support by state and federal funding of agricultural research in the United States.

The dependence on donor funding varies markedly among countries. At one extreme is Nigeria, which received only 6 percent of its funds from donors during the latter half of the 1980s. At the other extreme, countries as diverse as Burkina Faso, Cape Verde, Mali, Rwanda, Senegal, Tanzania, and Zambia got more than 60 percent of their support from international sources (table 6).

The fragile state of many African economies and the large array of demands placed on the public sectors in these countries make it likely that continued, and in some cases substantial, donor support for research will be necessary for some time to come. However, it is questionable if very high levels of support can be sustained indefinitely. Certainly serious thought should be given to the appropriate amount to spend on research, the design of mechanisms for disbursing donor funds to avoid crowding out domestic sources of support (which may well have been the case over the past few years at least), and the development of means by which funds can be mobilized and deployed to stimulate rather than dissipate the productive potential of the resources committed.

Table 6. Donor share of total agricultural research spending, 1991. [a]

Country	Local (%)	Foreign (%)
Botswana	85.5	14.5
Burkina Faso	22.2	77.8
Cape Verde	23.8	76.2
Côte d'Ivoire	53.5	46.5
Ethiopia	55.0	45.0
Ghana	64.1	35.9
Kenya	63.0	37.0
Lesotho	77.1	22.9
Madagascar	41.4	57.0
Malawi	44.6	55.4
Mali	34.0	66.0
Mauritius	90.0	10.0
Namibia	90.0	10.0
Niger	43.3	56.7
Nigeria	94.0	6.0
Rwanda	29.4	70.6
Senegal	35.9	64.1
Sudan	54.5	45.5
Swaziland	78.7	21.3
Tanzania	35.0	65.0
Zambia	20.2	79.8
Zimbabwe	74.2	25.8
Wtd avg (22 countries)	57.5	42.5

a\ South Africa reported no donor support in 1991.

Research Spending Intensities

To place agricultural research expenditures in a more meaningful context, it is common to relate them to the size of the agricultural sector as measured by agricultural output (AgGDP). Figure 5 provides an overview of the long-term development of this intensity ratio. The 19-country average increased throughout the 1960s and much of the 1970s, then declined steadily from a peak of 0.93 percent in 1981 to 0.69 percent in 1991, which is less than the level of intensity that prevailed 20 years earlier.

This sample average masks some major differences in research intensity among South

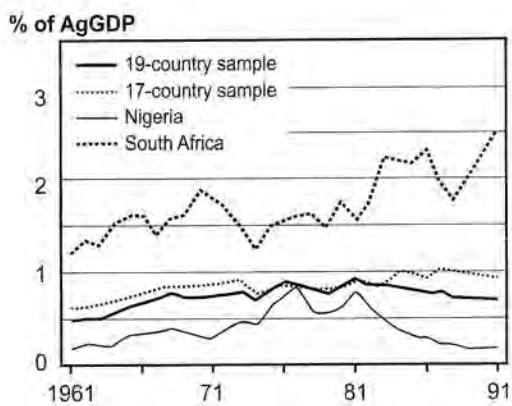

Fig. 5. Agricultural research expenditures in relation to agricultural output (AgGDP), 1961–91. Source: Based on data from World Bank (multiple years).

Africa, Nigeria, and the rest of Africa. South Africa's research intensity ratio trended upward for much of the post-1961 period. At 2.55 percent in 1991, it is significantly higher than the ratio in many other countries in the region (fig. 6). The instability in the ratio evident in figure 5 reflects weather-induced fluctuations in agricultural output rather than any significant year-to-year fluctuation in research spending.

In contrast to South Africa's persistent upward trend, Nigeria's research intensity ratio grew steadily throughout the 1960s and early 1970s but declined precipitously during the 1980s from 0.81 percent in 1981 to a 0.19 percent in 1991. In 1991 the 17-country African average, which excludes Nigeria and South Africa, was 0.92 percent compared with 0.69 percent for the 19-country sample that includes these systems.

Figure 6 presents the 1991 research intensity ratio decomposed by country and by source of funding. For the 23 countries, if all sources of funds are included, the average intensity ratio is 0.72 percent, ranging from 6.3 percent for Cape Verde to 0.19 percent for Nigeria. Measuring research intensities in terms of spending by research agencies from domestic sources only (i.e., net of international loan and grant funds) changes things considerably. The average spending intensity is lowered by a third to 0.48 percent. Moreover, the ranking of countries in terms of research intensities based on spending from all sources versus those intensities that include spending from domestic sources only are quite different. Botswana invests its own funds more intensively in agricultural research than any other country in the sample. A relatively large and quite prosperous nonagricultural sector

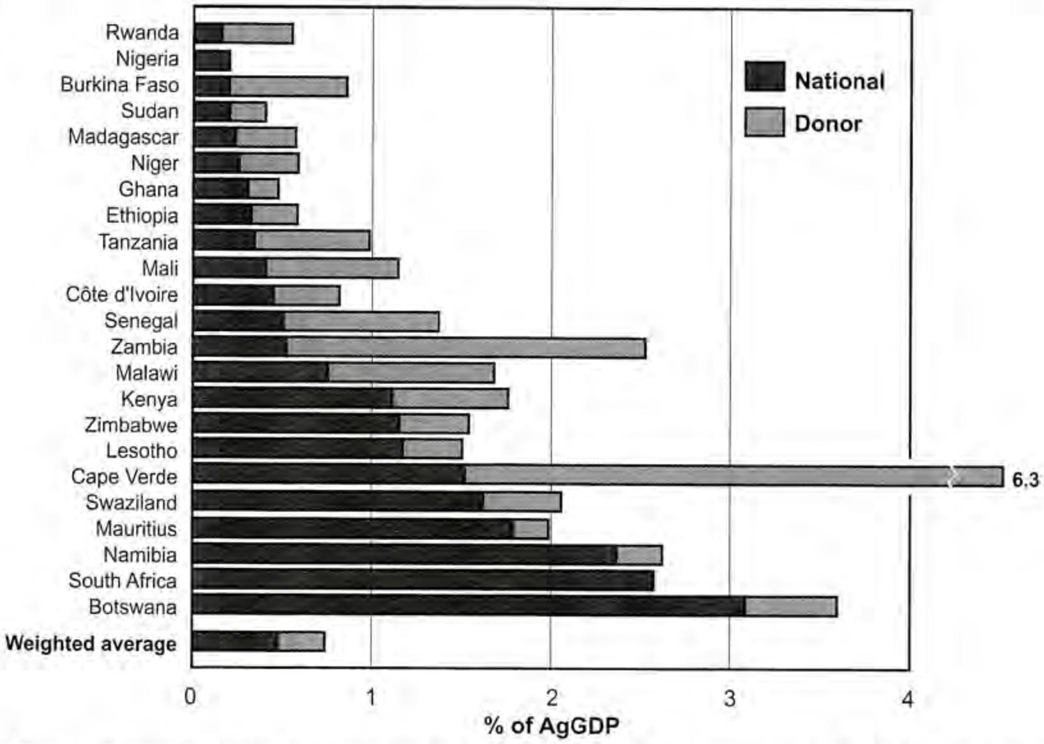

Fig. 6. Agricultural research expenditures by source or origin as a percentage of agricultural output (AgGDP), 1991. Source: Based on data from World Bank (multiple years)

forms the basis for this government support. At the other end of the spectrum are Burkina Faso, Nigeria, Rwanda, and Sudan, where local funds spent on research represent less than 0.2 percent of AgGDP.

Government Spending Intensities

Using a political economy framework to account for observed differences in government spending on agricultural research, Roe and Pardey (1991) looked at the share of total and agricultural spending by governments that is earmarked for agricultural research. Table 7 presents contemporary government spending shares for various African countries grouped by income level. Data for Nigeria and South Africa are shown separately—they have been excluded from the middle and high income classes, respectively, because they would dominate the averages.

Whereas the conventional research intensity ratio (i.e., agricultural research spending as a share of agricultural output) in South Africa has been rising and has been consistently among the highest of all African countries since 1961, agricultural research expenditures have constituted a falling and relatively small share of total government spending. In 1991 only 0.42 percent of total government spending in South Africa was on agricultural research compared with 0.59 percent in 1971 (table 7). In contrast the 16-country average share of research spending relative to total government spending was 2.5 times higher than that of South Africa. Aside from Nigeria, poorer African countries nowadays commit much more of their public-sector resources to agricultural research than Africa's richer countries. However, governments in poorer and richer African countries alike were giving less priority to agricultural research in 1991 than 1971.

Table 7. Research expenditures as a percentage of government expenditures in Africa.

Category [a]	1971	1981	1991
Low income (7)	1.14	0.88	1.14
Middle income (5)	1.91	1.16	1.13
High income (4)	1.57	1.16	0.58
Subtotal (16)	1.57	1.06	1.06
Nigeria	1.50	0.84	0.27
South Africa	0.59	0.44	0.42
Total (18)	0.97	0.76	0.60

Source: Government expenditure data from World Bank 1995 multiple years.

a\ Income classes: low, less than $750 (of 1991 per capita income, measured in 1985 PPP dollars); middle, $750 to $1,500; and high, more than $1,500. Number of countries shown in parentheses.

Conclusion

SubSaharan African countries made some progress in developing their agricultural research systems over the past three decades. The development of research staff has been particularly impressive in terms of numbers (a sixfold increase if South Africa is excluded), Africanization (from roughly 90% expatriates in 1961 to 11% in 1991), and improvements in education levels (65% of the researchers held a postgraduate degree in 1991). The indigenous capacity to train researchers also expanded, although the capacity to train at the M.Sc. and Ph.D. level is still limited.

Developments in agricultural research expenditures were considerably less positive. After reasonable growth during the 1960s and early 1970s, expenditures basically stopped growing in the late 1970s. Although there is considerable variation around this trend, it supports the notion that many African countries have lost ground in financing their agricultural research. Donor support has clearly increased in importance. Its share in the financing of agricultural research increased from 34 percent in 1986 to

43 percent in 1991. Although increased donor support somewhat compensated for declining government funding, it is unlikely that such high levels of support can continue indefinitely.

Many of the developments of the past decade in personnel, expenditures, and sources of support for public-sector research in Africa are clearly not sustainable. Richer and poorer African countries alike are giving lower priority to spending on agricultural research today than they did two decades ago. In addition, the rapid buildup of research staff is not accompanied by an equal growth in financial resources. Spending per scientist has continuously declined during the past 30 years, but most dramatically during the 1980s. Resources are spread increasingly thin over a growing group of researchers, which has negative effects on the efficiency and effectiveness of agricultural research. A turnaround is needed, either by increasing the funding for agricultural research or by a painful and likely wasteful reduction of research staff.

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The Institute of Agricultural Research: Its Role in the Development of Ethiopian Agriculture

Getinet Gebeyehu, Tesfaye Zegeye, Abebe Kirub, and Kiflu Bedane

The Institute of Agricultural Research (IAR) of Ethiopia was established by Order No. 42 on 23 February 1966. IAR's establishment order states that its sphere of activity in agriculture, livestock, and forestry is national. Although agricultural research was undertaken in various forms in Ethiopia before the establishment of IAR, a number of reports and authorities agree that discussions of the reciprocal relations between agricultural research and development—the twin tools for effecting socio-economic equity—began with the inception of IAR.

IAR was established to coordinate agricultural plans, programs, and devices to ensure the effective application of knowledge derived from research. IAR's mission statement provided a useful initial focus, although it is phrased in generalized and enhanced terms since its primary purpose was to define long-term aspirations. The aspirations were, thus, translated into the following explicit institutional objectives:

- formulating national agricultural research guidelines
- coordinating national agricultural research
- undertaking research in its centers and subcenters located in various agroecological zones of Ethiopia

The most prominent mandatory task of IAR is undertaking full-fledged agricultural research involving crops, livestock, agricultural mechanization, and farming systems.

Since its beginning, IAR has been a semi-autonomous full-time research institution functioning under the general supervision of the Board of Directors, drawn from various ministries and organizations that are directly or indirectly involved in agricultural development in Ethiopia. However, throughout its history, there have been several changes in the composition of the Board of Directors, which usually coincided with changes in government and political outlooks.

IAR has become a highly formalized research structure with accompanying flexibilities in its research management and technical climate. This has led to considerable technology generation and transfer endeavors and created more favorable conditions for managers, researchers, and support staff alike.

After the start of research in IAR, national committees, conferences, workshops, symposia, informal internal reorganizations, the development of national agricultural policies and strategies, and international assistance have received considerable attention as important aspects of its organizational activities. Nevertheless, IAR's

Getinet Gebeyehu is Deputy General Manager for Research, **Tesfaye Zegeye** is Agricultural Economist, **Abebe Kirub** is Head, Information Services, and **Kiflu Bedane** is Research and Extension Coordinator, Institute of Agricultural Research, Addis Ababa

organizational strength is in helping socialize and externalize agro-technologies generated for the target public to absorb.

Function, Organization, and Coordination

Over the last quarter century several initiatives have been launched to improve the functioning, organization and coordination of agricultural research in IAR. These initiatives have resulted in well-coordinated, organized, and functionally improvable and long-lasting research foundations through the following contemporary approaches.

National commodity research (NCR) involves commodities that have been given national priority. At present agricultural implements, coffee, cotton, maize, sorghum, teff, and wheat have been given national commodity status. When needed, more commodities are to be upgraded to a national priority.

NCR is organized and coordinated by a national commodity research team headed by a team leader. The team is composed of researchers drawn from different specializations. NCR acquires its annual budget from the government or special funds administered by IAR. In its technical and administrative function, NCR is semi-autonomous and, hence, its accountability is to the IAR management.

The NCR programs are coordinated at research centers where the commodity as a biological organism (crop) is dominant in the locality and where facilities (human and other material resources) are relatively adequate (table 1). NCR experiments are executed in both IAR and non-IAR cooperating or participating institutions.

For crops that are not yet promoted at a commodity level, researchers are also organized in teams. In principle the organization of these teams is similar to that of NCR except that they are thinly stretched and their autonomy is minimal. The noncommodity teams and disciplines that are not part of the NCR are functionally organized and coordinated by centers' departments (table 2).

Research is undertaken by several departments in the different research centers, subcenters, trial sites, and farmers' fields. The Research-Extension Liaison Committee (RELC) represented by regional offices of the Ministry of Agriculture and farmers was an important forum for discussing and exchanging ideas on production constraints, research programs, and research findings. Recently the Input Coordination Unit replaced RELC as an important interface between research and extension at all levels of the government structure.

Table 1. National commodity research coordinating centers.

Center	Commodity
Bako	Maize
Holetta	Teff
Kulumsa	Wheat
Melkasa	Sorghum and agricultural implements
Melko	Coffee
Melka Werer	Cotton

Table 2. Research disciplines of IAR.

Agricultural economics	Food science
Agro-meteorology	Horticulture
Animal feeds and nutrition	Soil science and water management
Animal health	Research-extension
Animal production	Bacteriology
Agronomy and/crop physiology	Biotechnology
Agroforestry	Mycology
Crop protection (plant pathology and entomology)	Nematology
Field crops improvement (breeding and genetics)	Virology

Both NCR and departments are engaged in many experiments, usually more than 1,000 annually, involving crops, livestock, agricultural mechanization, natural resources and agricultural economics.

The IAR management provides centralized and decentralized technical and administrative assistance in support of NCR and other research programs.

Research and Technology-generation Processes

Research Reviews

Briefly, IAR researchers design experiments based on their interpretation of farmers' circumstances and their experiences while working with farmers and extension agents. The proposals of researchers are evaluated by their center colleagues and the center technical committee for their scientific, technical, and socio-economic qualities.

Proposals approved at center level are presented at the IAR National Research Program Review Meeting. At this stage, priorities, thrusts, and goals of proposals are discussed. Proposals approved are then presented to the National Agricultural Research Council (NARC) in order to eliminate duplication of efforts among agricultural research institutions, to properly coordinate research activities at national level, to critically examine their appropriateness in relation to the national agricultural research policy and strategy, and to properly allocate annual research budgets. The NARC meeting is the final stage of the research program review process.

After the review by NARC, approved experiments of IAR are documented and published in the Research Program Directory of the institute. The progress of experiments is reported, on quarterly and cumulative annual basis, to the IAR management for evaluation and monitoring purposes.

Technology Generation

With respect to its broad institutional tasks, IAR goes through a series of fundamental steps to generate technology or information to users who will implement and integrate it into their farming system, as they see it fit. In this context, therefore, several steps and procedures with the assumption that they serve as reference points, consulting and reconciliation stages are considered. The basic mechanisms are presented below.

On-station Research. This is the initiation stage in the process of technology generation. It is the longest segment in the process. A number of scientific investigations are undertaken over a certain period of time, mainly at research centers and cooperating institutions or organizations. The process is managed by researchers. Results with potential applicability will be further tested on disadvantaged farmers' fields.

On-farm Research. Experiments with promising results are tested on larger farmers' plots by agricultural economists in collaboration with other researchers. The economics of inputs in relation to yield is a major consideration at this stage. This approach is necessary not just to drive down the cost of inputs but also to build up the independence and self-confidence of farmers.

Verification and Release. Until the 1980s, technologies generated by IAR were recommended for users mainly by researchers and approved by the National Crop Improvement Conference. This approach had drawbacks, and in the early 1980s, the National Variety Release

Committee (NVRC) was formed to verify and release crop varieties. Technologies, mainly crops, in the pipeline for release are verified by the NVRC. The committee is drawn from different agricultural research and development organizations. IAR is a member of NVRC.

A technology will be approved by NVRC if it shows a relative advantage over existing technologies. Verification trials are either multi-site or cover a considerable area or region. The verification step is essential to avoid unsustainable release of technologies. Nevertheless, to date, not all technologies generated by IAR have gone through a formal technology release process.

Demonstration and Popularization. Technology approved by the NVRC will be demonstrated and popularized to farmers by the Research Extension Division of IAR in close cooperation with extension agents. This is a stage of reconciliation of new technologies and farmers. It is also vital for matching, filtering, or modifying extension pathways through periodic, tailor-made training of subject-matter specialists and front-line extension agents of the Ministry of Agriculture.

Follow-up. Researchers closely monitor released technologies to detect any breaks in the genetic makeup or the occurrence of environmental stresses that may reduce the potentials of the technology. There aim is to add essential elements into the technology's biological constitution and consequently update packages of agronomic practices to make it more suitable for exploiting a wide range of environments.

Technologies Generated by IAR. Some years after the establishment of IAR, most research materials—crop varieties and livestock breeds—were considered obscure and confined mainly to research centers. There were tremendous biological and social constraints to introducing them widely. IAR researchers began to explore the possibilities of re-modeling certain crops and livestock of potential importance to the country. As a result, farmers have begun acquiring crop varieties, crossbred cattle, and improved agricultural implements. Tables 3, 4, and 5 present technologies generated by IAR. In the course of its history, IAR has released more than 250 agro-technological innovations, which have been incorporated into the Ethiopian agriculture.

Table 3. Summary of technologies (innovations) and their production status.

Technology group	Total no.	Innovations (no.) Existing	Under production
Cereals	6	83	44
Pulses	3	16	16
Oilcrops	7	32	28
Fiber crops	2	17	8
Coffee	1	16	16
Spices	3	5	5
Roots and tubers	2	8	7
Fruits	14	25	21
Vegetables	3	12	9
Forage crops	18	18	18
Livestock	3	14	6
Agricultural implements	4	4	4
Total	**66**	**250**	**182**

Table 4. Technologies generated in 5-year periods.

Years	Technologies (no.)
1966–70	10
1971–75	65
1976–80	81
1981–85	36
1986–90	38
1991–94	16
Undated	4
Total	250

Technology Diffusion Mechanism

The impacts of research investments can only be assessed through changes in farm productivity. A strong and efficient national agricultural extension service that stimulates the adoption of recommended scientific farming techniques and ideas is thus a prerequisite for successful technology diffusion.

Table 5. Varieties of the major cereal crops currently under production.

Variety	Adaptation zone: Altitude (m)	Adaptation zone: Rainfall (mm)	Seed rate (kg/ha)	Potential yield (t/ha)
Wheat				
Enkoy	1,850–2,800	500–800	125–150	4.0–6.0
Dereselign	1,850–2,800	400–600	125–150	4.0
K6295 4A	1,850–2,750	>600	125–150	4.0–6.0
K6290 Bulk	1,850–2,150	500–600	125–150	4.0–6.0
ET-13	1,800–2,900	>600	125–150	5.5–7.0
HAR-1709	1,800–2,800	>600	125–150	4.2–5.1
HAR-710	1,900–2,800	>600	–	4.2–7.0
HAR-1685	1,900–2,600	>600	–	4.5–7.0
Malting barley				
Beka	>2,300	600–100	75–100	
Holker	>2,300	600–100	75–100	
Food barley				
ARDU 12-60B	2,200–2,800 700–1,000		100–125	3.5–4.2
HB 42	>2,300; 700–1,000		100–125	4.0–4.2
Teff				
Cross-37	1,860–2,000	134–500	25–30	1.4–1.6
DZ-01-196	1,800–2,400	300–700	25–30	1.4–1.6
DZ-01-354	1,600–2,400	300–700	25–30	1.7–2.2
DZ-01-87	1,800–2,000	400–700	25–30	1.7–2.2
Gibe (DZ-01-255)	1,520–1,750	550–850	25–30	1.4–1.8
DZ-01-974	1,800–2,400	300–700	25–30	1.5–2.0
DZ02-358	1,800–2,000	134–500	25–30	1.5–1.8
Sorghum				
AL-170	1,900–2,000	870–900	–	3.0–5.5
ETS-2752	1,900–2,000	870–900	–	3.0–5.5
IS-9302	1,600–1,900	>900	5–10	3.5–5.0
Birmash	1,600–1,900	>900	5–10	3.0–6.9
Gambella 1107	<1,600	<600	5–10	2.8–5.0
Dinkmash	<1,600	<600	5–10	3.0–5.0
76T # 23	<1,600	<600	5–10	2.5–4.0
Seredo	<1,600	<600	8–10	2.0–4.0
Maize composites				
A511	100–1,900	600–900	25–30	4.0–5.5
AL Composite	1,600–2,300	>900	25–30	7.5–9.5
Beletech			25–30	7.0–9.0
Katumani	<1,500	> 600	25	1.5–3.0
Maize hybrids				
CG4141	1,300–1,900	600–1,000	25–301	
BH660	1,600–2,200	>650	25–30	8.0–10.0
BH140	1,300–1,900	600–1,000	25–30	11.0–12.0
BH540	1,300–1,900	600–1,000	25–30	5.0–8.0

Agricultural extension, and thus technical advice to farmers, began in the 1950s with the establishment of the Alemaya College of Agriculture. In the early 1960s, the extension function of the college was transferred to the Ministry of Agriculture, which more or less followed the conventional approach to extension. This period also marked the beginning of the several structural changes and reorganizations that have been taking place in the national agricultural extension service. The structural advantage of the existence of research and extension that the college was lost. Little technology had been generated at that time, and extension activities were mainly limited to animal health practices and afforestation.

When peasant agriculture gained more attention during the third 5-year development plan (1968–73), comprehensive agricultural projects like Chilalo Agricultural Development Unit and Wolaita Agricultural Development Unit were initiated. Besides agricultural extension proper, these projects included development of infrastructural services like roads, water, etc., and were intended as models to be expanded to other areas later.

The comprehensive approach to extension was also gradually phased out because the operating cost was found too great to be duplicated to other areas. Nevertheless, the program had a consistently positive effect, and major gains in extension knowledge in the project areas were made. The heavy financial demands of the comprehensive packages led to the initiation of the minimum package projects in the 1970s under the Extension and Project Implementation Department. The minimum package extension approach comprised limited extension components like inputs, credit, and extension advice. It had a wider area coverage though it was limited to 10 kilometers of either side of all weather roads. This project continued until 1985 when the training and visit system was introduced.

Despite various extension efforts in the past, the performance of agriculture in the country has not been improving. Rainfall remains the main determinant of agricultural output, and annual variation in amount and distribution lead to wide production swings.

Despite the available technologies, which if properly utilized could increase agricultural productivity, the majority of Ethiopian farmers still use traditional agricultural practices. Effective agricultural technology diffusion is an essential but not sufficient condition for technology adoption. Preconditions for successful extension efforts have been difficult, if not impossible, to put in place.

The major problem in the technology diffusion process is to make the products of technology physically available to farmers. Farmers do not have easy access to the products necessary for science-based agriculture, such improved varieties, fertilizers, and crop-protection products. Some agricultural technologies like improved seeds are not produced in sufficient quantities.

There are also constraints from the farmer's side. Few farmers have cash resources to purchase agricultural inputs. Credit for input purchase exists, but it involves administratively cumbersome procedures that often repel farmers.

The Sasakawa Global (SG 2000) project initiated in 1993 has proved that technologies generated by the national agricultural systems, if properly utilized, could at least double and even triple yields of major cereals grown in the country. The secret behind the SG 2000 aggressive technology-transfer program is simply filling the major gaps that had existed in the various extension systems of the past. These include access to technologies that are developed by the Institute of Agricultural Research and other inputs and making them physically available through the provision of credit. Intensive, practical training of extension workers from the central staff down to the development agents and the improvement of mobility of extension workers through provision of vehicles, motorcycles, and bicycles have greatly facilitated the success of the program.

An other strength of the program is its major effort to more tightly link research, extension, and input distributors, which is a key issue for a successful agricultural technology-transfer process.

The experience of the SG 2000 project has greatly contributed to the formulation of an extension strategy for the country, which is in its first year of implementation. The present participatory demonstration and training extension system strategy is a synthesis of the SG 2000 approach, which uses large demonstration plot, usually one-fourth to half a hectare, to demonstrate improved farming practices. Training is given both to the extension staff and farmers. Regular visits to demonstration plots provide ample opportunity to discuss with farmers the problems encountered in the process. Though the program is in its infancy, there are already an indications that we are on a right path provided that the present momentum can be maintained or strengthened.

Capacity-building in Agricultural Research: Trend and Implication

Finance

The Institute of Agricultural Research has grown both in size and complexity over the last 29 years. One of the major tasks during these years was institution building and human resources development.

The main support for agricultural research in Ethiopia is public funding. The justification is that the public as a whole benefits from the application of research output. Not only is the production of sufficient food crops, industrial crops, and export crops promoted, but costs to the consumer are generally decreased. Also it would be unrealistic to expect that such a large industry as agriculture, fragmented as it is into numerous small production units, could itself maintain a viable research organization.

Agricultural research in Ethiopia is also financed by bilateral and multilateral donors. Significant financial assistance obtained during the first 10 years of the establishment of IAR was mainly for capacity building, particularly laboratory facilities, training, and technical assistance (in areas where there was lack of trained workforce). This continued in the 1980s and 1990s. During this time, IAR was able to develop its infrastructure (offices, laboratories, greenhouses, cold storage, roads, etc.), facilities (such as laboratory equipment, farm machinery, seed cleaning machines), and also human resources. The international agricultural research centers are not donors in the strict sense, but they contribute to agricultural research in Ethiopia by providing improved genetic materials for breeding and varietal screening, training, and networking.

The government has also allowed the IAR to retain income generated from sales of research products such as seed of improved varieties. The funds generated from sales, though small in amount, are used for maintaining and improving facilities and, in rare cases, for operating expenses.

The mean annual budget allocated to IAR from 1984/85 to 1994/95 was EB36 million (table 6). The main sources of funds were the government treasury and small grants from institutions such as SAREC through ICARDA, UNDP, FAO, EU, IDRC, and the Netherlands government. The Ethiopian government's contribution ranged from 62 percent in 1984/85 to 94 percent in 1994/95. On the average, the government's contribution was 83 percent of the total funds allocated to IAR (table 6).

Table 6. Budget allocated to IAR by source of funds, 1984/85–94/95.

Year	Amount (EB millions) Govt. (Local)	Aid (External)	Total	Government share (%)
1984/85	16.8	10.2	27.0	62
1985/86	31.7	4.9	36.6	87
1986/87	39.8	6.2	46.0	87
1987/88	33.8	2.6	36.4	93
1988/89	26.0	2.0	28.0	93
1989/90	35.5	11.5	47.0	76
1990/91	27.2	14.8	42.0	65
1991/92	21.6	9.9	31.4	69
1992/93	36.8	2.2	39.0	94
1993/94	28.2	3.0	31.2	90
1994/95	30.5	1.9	32.4	94
Mean	29.1	6.3	36.1	83

Source: Planning & Project Service, IAR

However, on the average, the total funds were only 0.64 percent of the agricultural gross domestic product, calculated at constant factor cost, and the funds allocated from the central treasury of the government were only 0.61 percent (table 7). A 1981 World Bank sector policy paper on agricultural research (cited in FAO 1994) argued that 2 percent of the agricultural gross domestic product would be an appropriate investment level for countries in which agriculture is the key economic sector.

Arnon (1975) indicated that in advanced countries over 2 percent of the total GDP has usually been allocated for research and development. By contrast, in developing countries the figure is usually nearer 0.1 to 0.4 percent (table 8). However, it is generally considered that at least 1 percent of GDP

Table 7. Fund allocated to IAR as percentage of agricultural GDP (at constant factor cost).

Year	Agricultural GDP (EB millions)	Total funds Amt (EB millions)	vs. AgGDP (%)	Funds from local sources Amt (EB millions)	vs. AgGDP (%)
1984/85	4,241	27.0	0.64	16.8	0.40
1985/86	4,932	36.6	0.74	31.7	0.64
1986/87	5,832	46.0	0.79	39.8	0.68
1987/88	5,696	36.4	0.64	33.8	0.59
1988/89	5,688	28.0	0.49	26.0	0.46
1989/90	5,984	47.0	0.78	35.5	0.59
1990/91	6,151	42.0	0.68	27.2	0.44
1991/92	5,867	31.4	0.54	21.6	0.37
1992/93	6,241	39.0	0.62	36.8	0.59
1993/94	5,907	31.2	0.53	28.2	0.48
Mean	5,654	36.4	0.64	34.2	0.61

Source: MOPED 1994.

should be the minimum level to effectively support research in any country.

When these figures are compared with the funding situation in Ethiopia (table 7), the level of funding is grossly inadequate but about the same as the levels shown in table 8 for developing countries.

Table 9 divides funds allocated to IAR into investment, salary, and operating funds. As indicated, in most years salaries were less than half of the total funds allocated. Because research staff are still on civil service pay scales and grades, there is a steady loss of valuable staff to NGOs and international and other organizations with better salary, facilities, and working environment.

Table 8. Expenditure on research and development as percent of GDP.

Country	1960	1965–1970
USA	2.8	2.8 (1969)
USSR	2.3	4.2 (1970)
UK	2.7	2.4 (1968)
Ghana	0.2	0.2 (1966)
Lebanon	0.1	0.3 (1967)
Philippines	0.1	0.2 (1965)
India	0.1	0.4 (1969)
Pakistan	0.1	0.1 (1969)

Source: Arnon 1975.

During the last 10 years, IAR has substantially improved its infrastructure particularly in terms of office and laboratory space, laboratory equipment, farm machinery, and roads. That is why the funds allocated to investment ranged between 26 percent and 50 percent during the years under consideration. However, operational funds have been insufficient to cover the costs of critical materials such as chemicals, fertilizers, and spare parts.

Among the research programs, the bulk of the funds allocated to IAR goes mainly to crops-related research because government development plans and strategies emphasized the attainment of food self sufficiency. Even though the crop sectors make important contributions to the self-sufficiency objectives of the government in the short-term, research in other sub-sectors such as livestock, natural resources, farm machinery, and agricultural economics should be given equal importance.

Human Resources Development

A trained workforce in the sciences constitutes the foundation for long-term sustainable agricultural research. The quality

Table 9. Approved budget for investment, personnel and operation costs of IAR, 1984/85–93/94.

	Amount (EB millions)				Share (%)		
Year	Investment	Personnel	Operation	Total	Investment	Personnel	Operation
1984/85	13.4	8.6	4.9	27.0	50	32	17
1985/86	14.5	13.5	8.6	36.6	40	37	23
1986/87	21.2	15.3	9.4	46.0	46	33	21
1987/88	16.5	12.7	7.2	36.4	45	35	20
1988/89	9.4	12.7	5.9	28.0	34	45	21
1989/90	19.0	14.6	13.3	47.0	41	31	28
1990/91	16.9	13.5	11.6	42.0	40	32	28
1991/92	8.9	13.4	9.0	31.4	28	43	29
1992/93	15.0	12.6	11.3	39.0	39	32	29
1993/94	8.0	11.5	11.8	31.2	26	37	37
1994/95	8.3	12.3	11.7	32.4	26	38	36
Mean	13.7	12.8	9.5	36.1	38	36	26

of research depends primarily on the skill, knowledge, and competence of researchers and on the training the scientists have acquired in their own disciplines (Elias 1981). In regard to the human resources, the overall concern is to ensure continuity and an adequate supply of appropriately trained professionals for the research institute. To undertake productive research leading to increased agricultural development, IAR depends heavily on high-caliber experts. In addition to their research roles, these individuals may also be expected to take on management and leadership responsibilities. Three methods are used to train agricultural research personnel in IAR: academic training, on-the-job training, and short-term training. All the three types are equally important in developing qualified researchers. Academic training helps to form a sound base for a researcher and to bring qualitative change in the research undertaking. Short-term and on-the- job training help to develop skill, knowledge, and efficiency (Elias 1981). It is also necessary that trained personnel be provided with facilities to demonstrate their competence and training. Through 1993, IAR provided long-term training to 332 experts with funds from various sources. Only about 41 percent are now serving the institute, 9 percent are still pursuing their education abroad and in the country, and 50 percent of those trained by IAR either have returned to the country and joined other institutions or never returned to the country.

The high attrition rate seriously affects the human resources development effort. The most important explanatory factors are:
Research staff or personnel are still on civil service pay scales and grades.
Most research centers of IAR are located in remote areas far from towns and cities, where services such as education, healthcare, and employment opportunities for family members of the researchers are scarce.

Therefore, it is assumed that those research personnel who have not returned to the institute either have received better remuneration elsewhere and or have joined institutions with better working conditions and provisions.

In July 1995, 23 Ph.D.'s, 74 M.Sc.'s, 121 B.Sc.'s, and 201 diploma holders (table 10) were working in various disciplines and across different research centers. A serious imbalance is observed among different disciplines in the Institute. Sixty percent of the Ph.D.'s, 68 percent of the M.Sc.'s, 71 percent of the B.Sc.'s, and 59 percent of the diploma holders are conducting research in

Table 10. IAR staff by qualification and by division (July 1994).

Division	Ph.D.	M.Sc.	DVM	B.Sc.	Diploma
Plant science	14	50	–	86	119
Farm implements	–	4	–	7	5
Agricultural economics	–	2	–	7	5
Livestock	2	8	2	13	24
Soil science and water management	6	7	–	7	21
Research extension	1	2	–	1	6
Food science	–	1	–	–	1
Farm management	–	–	–	–	20
Total	**23**	**74**	**2**	**121**	**201**

Source: IAR

plant sciences. Ten percent of M.Sc. holders are in livestock and 9 percent are in soil and water management, while at the Ph.D. level soil and water management has more professionals than the livestock and farm implements disciplines.

Technologies Developed by IAR: Implications for Agricultural Development in Ethiopia

The impact of the recent droughts and the effect of insufficient and unpredictable rainfall on agricultural production have a number of times focused attention on the dominant role of agriculture in Ethiopia. This role involves not only feeding the burgeoning population, but also providing more employment in the rural sector and increasing exports for foreign exchange earnings. Ethiopia is not self-sufficient in staple food even in good years. In addition, with rapid population increase, food self-sufficiency is becoming unapproachable as opportunities for expanding cultivated area disappear. With stagnating yields, there are shortfalls in basic food supplies even in years of good rainfall. In drought years, the downward trend of per capita agricultural production is accentuated, environmental degradation is increased, and the vulnerability of many parts of the country to this natural phenomenon becomes evident.

Clearly then, increased productivity in good years and bad is essential for the future well-being of agriculture and for all those who depend on it. However, it is not only a matter of increasing productivity per se. Improved seed, improved cultural practices, fertilizers, etc., can certainly improve productivity, but they must do so within a system that is environmentally sustainable and economically viable for the country and the farmers. Agricultural research provides the technology to do this. Without it, sustained increases in productivity are impossible. Research plays a crucial role in (*a*) generating and adapting technologies that can increase agricultural productivity, (*b*) generating technologies that can provide productive employment in rural areas, and (*c*) contributing to the food security of the nation and the family.

Many varieties with suitable technology packages have been developed by IAR (table 5) and varieties of the five major cereal crops have been given to the Ethiopian Seed Enterprise (ESE) for further multiplication and distribution to users. Only small amounts of improved varieties of other field crops and horticultural crops are produced by IAR.

The potential of technologies developed by the institute can be illustrated using the amount of seed produced by the ESE for the major cereal crops—teff, maize, barley, sorghum, and wheat—to develop various scenarios. The average seed produced from 1980/81 to 1989/90 by the ESE was used to determine the area planted with improved varieties of the five major cereals (table 11). On that basis, out of the total area cultivated with teff, maize, barley, sorghum and wheat only 1.0, 16.9, 1.8, 3.7 and 15.7 percent, respectively, were planted with certified seeds of improved varieties. However, taking breadwheat and maize as examples, when seed from both the formal seed sector and the informal seed sector are considered, over 80 percent of the wheat area and 50 percent maize area are covered with improved varieties.

At present, Ethiopia produces 780,000 tonnes of breadwheat annually on 390,000 hectares of land. The monetary value of this output is estimated to be EB1.17 billion. Eighty percent (312,000 ha) is planted with improved breadwheat varieties bred or selected locally and distributed to farmers during the last 15 years. In the same period, the breadwheat area in the country increased by 160 percent. As a result of the use of high-yielding varieties, the annual breadwheat production increased fivefold, from 150,000 tonnes to 780,000 tonnes.

The release and distribution of these high-yielding disease-resistant and widely adapted breadwheat varieties acceptable to farmers has doubled the national yield to 2 t/ha.

Taking into account the cost of production, and introducing variable costs of improved seed, fertilizer, and herbicide, the high-yielding breadwheat varieties had a marginal rate of return of up to 360 percent compared with the local breadwheat cultivar. In terms of total monetary value, the high-yielding breadwheat varieties generate EB 936 million annually.

In maize, though several improved composite varieties are available locally, foreign sources of hybrid seed have been important for many years. For instance, from 1986 to 1991 a total of EB 11.1 million was spent by the ESE to purchase maize seed. With the development of the maize hybrids BH 140, BH 660, and BH 540, this amount of money could easily be saved.

For computing the incremental level of production as a result of the provision of certified seed and fertilizer, the current national yield (derived by dividing the mean total production by the mean total area for each cereal) and the potential yields (yields that could be attained if all technological packages are used properly) of improved seeds were taken into consideration. The incremental yield produced is estimated to be 720,700 tonnes (table 11). The amount of fertilizers required for use in combination with the improved seed based on the blanket recommendation of 100 kg/ha diammonium phosphate and 50 kg/ha of urea, is calculated at about 48,000 tonnes. Assuming that on the average about 400,000 tonnes of DAP and urea are imported annually, then 352,000 tonnes will remain to be used with local landraces, covering 2.3 million hectares of land. If an additional 400 kg/ha is attained by planting the local varieties with fertilizer, a total of 939,000 tonnes will be produced

Table 11. Estimated production of major cereal crops under traditional and improved technology.

Crop	Avg area (000 ha)	Improved seed: Produced (000 t)	Improved seed: Area planted (000 ha)	Improved seed: Share of total land in crop (%)	Traditional technology: Yield (t/ha)	Traditional technology: Production (000 t)	Improved technology: Yield (t/ha)	Improved technology: Production (000 t)	Output gain[b] (000 t)
Teff	1,327	0.34	13.6	1.0	0.9	12.2	2.0	27.1	14.9
Maize	925	4.70	156.7	16.9	1.7	266.4	4.5	705.1	438.7
Barley	893	1.59	15.9	1.8	1.2	19.1	2.3	36.6	17.5
Sorghum	817	0.75	29.8	3.7	1.4	41.8	2.5	74.6	32.8
Wheat	657	12.90	103.2	15.7	1.1	113.6	3.2	330.4	216.8
Total	4,619	20.28	319.2	6.9		453.0		1,173.7	720.7

a\ Annual average by Ethiopian Seed Enterprise, 1980/81–89/90.
b\ Due to improved seed and fertilizer.

from the 2.3 million hectares of land. However, as can be seen in table 11, the total amount of cultivated area planted with improved technology, as derived from seed produced by the ESE, is only 6.9 percent.

Assuming six scenarios in which 10 to 60 percent of the land cultivated to produce the five most important cereals (table 12), and also assuming that improved technologies such as seed, fertilizer, cultural practices, and good management are applied to the area calculated using the six scenarios, the total production calculated at each scenario level is found to cover 177, 147.5, 118, 88.5, 59.2, and 29.5 percent, in descending order, of the food gap at a consumption level of 225 kilograms per person per year (2,100 kcal).

For example, when 40 percent of the land is in improved technology and the remaining cultivated land is under traditional cultivation methods, the total output of the five cereal crops will amount to 8.6 million tonnes (5.2 million tonnes from improved technology and 3.4 million tonnes from traditional technology) (tables 12a and 12b), amounting to 114 percent of the 1993/94 domestic supply of 7.5 million tonnes (Tesfaye and Debebe 1995).

The amount of seed required for each crop for the six scenarios is presented in table 13. When 10 to 60 percent of the land cultivated for each crop is covered with modern technologies, the total seed requirement ranges from 25,000 to 151,000 tonnes. The fertilizer requirement, which is calculated on the basis of the blanket recommendation of 100 kg/ha of diammonium phosphate and 50 kg/ha of urea, amounts to 69,000, 139,000, 208,000, 277,000, 346,000, and 416,000 tonnes for the six scenarios respectively.

Table 12a. Hypothetical case: Assuming that 10% to 60% of land area in major cereal crops is planted with improved technology.

Area in improved tech.	Teff		Maize		Barley		Sorghum		Wheat		Total production (000 t)
	Area (000 ha)	Prod. (000 t)	Area (000 ha)	Prod. (000 t)	Area (000 ha)	Prod. (000 t)	Area (000 ha)	Prod. (000 t)	Area (000 ha)	Prod. (000 t)	
10%	133	265	93	416	89	205	82	204	66	210	1,302
20%	265	531	185	833	179	411	163	409	131	420	2,603
30%	398	796	278	1,249	268	616	245	613	197	631	3,905
40%	531	1,062	370	1,665	357	822	327	817	263	841	5,206
50%	664	1,327	463	2,081	447	1,027	409	1,021	329	1,051	6,508
60%	796	1,592	555	2,498	536	1,232	490	1,226	394	1,261	7,809

Table 12b. Production from land in major cereal crops under traditional technology after deducting hypothetical area under improved technology.

Area in improved tech.	Teff		Maize		Barley		Sorghum		Wheat		Total production (000 t)
	Area (000 ha)	Prod. (000 t)	Area (000 ha)	Prod. (000 t)	Area (000 ha)	Prod. (000 t)	Area (000 ha)	Prod. (000 t)	Area (000 ha)	Prod. (000 t)	
90%	1,194	1,075	833	1,415	804	964	735	1,029	591	650	5,134
80%	1,062	955	740	1,258	714	857	654	915	526	578	4,564
70%	929	836	648	1,101	625	750	572	801	460	506	3,993
60%	796	717	555	944	536	643	490	686	394	434	3,423
50%	664	597	463	786	447	536	409	572	329	361	2,852
40%	531	478	370	629	357	429	327	458	263	289	2,282

Conclusion

It is no exaggeration to conclude that the technological opportunities offered by IAR give it a central role in agricultural development in Ethiopia. This is based on the assumption that research is a major engine of growth in agriculture, that there will be close liaison between research and extension, and that policies and strategies will stay on track. It is important that research and extension be well coordinated. The factors of technology generation and transfer should be equally mobile. Matching of technology generation and transfer will provide great benefits in the long run.

In the literature, a number of studies indicate that the per capita utilization of improved seed and fertilizer in Ethiopia is low compared with other countries in sub-Saharan Africa. However, as indicated in the hypothetical scenarios, the amount of fertilizer imported into the country is sufficient to raise productivity if it is used with seed of improved varieties and better cultural practices. Improved seed is one of the major components for increasing agricultural productivity. Its production and effective utilization will enable the country to become self-sufficient in food.

One urgent issue that needs consideration is to produce seeds in response to demand. Changing the attitudes and knowledge of farmers requires the devotion and dedication of all concerned parties at federal, regional, wereda, and grassroots level. Seeds have to be available in sufficient quantities to meet the demands of peasant producers and commercial farms. Hence, ESE, private investors who want to enter into seed production, and cooperatives should be encouraged and given support that will enable them produce the required quantities and qualities of seeds.

IAR also deserves commitment by the government to be able to maintain its research staff, which is at the center of the development of research programs and technology. It must be recognized that capacity-building in terms of strengthening its human resources through offering formal training (M.Sc. and Ph.D.), in-service training, and sabbaticals has a positive impact on the agricultural development of the nation. In the long run, the government needs to strengthen universities so that they can provide training up to the level of Ph.D.

Table 13. Seed requirement for production levels under scenarios in table 12.

Area in improved tech.	Teff		Maize		Barley		Sorghum		Wheat		Total production (000 t)
	Area (000 ha)	Seed req. (000 t)	Area (000 ha)	Seed req. (000 t)	Area (000 ha)	Seed req. (000 t)	Area (000 ha)	Seed req. (000 t)	Area (000 ha)	Seed req. (000 t)	
10%	133	3.3	93	2.3	89	8.9	82	0.8	66	9.9	25
20%	265	6.6	185	4.6	179	17.9	163	1.6	131	19.7	50
30%	398	10.0	278	6.9	268	26.8	245	2.5	197	29.6	76
40%	531	13.3	370	9.3	357	35.7	327	3.3	263	39.4	101
50%	664	16.6	463	11.6	447	44.7	409	4.1	329	49.3	126
60%	796	19.9	555	13.9	536	53.6	490	4.9	394	59.1	151

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Extension, Technology, and Efficiency in Agriculture in sub-Saharan Africa

Robert Evenson

The countries of sub-Saharan Africa have a number of features in common. Most are in the difficult process of nation building after long periods of colonial government. Most have historically high rates of population growth. Many are small countries with diverse land and water resources. Most are in the early industrialization phase of economic development. Most are in the "pre-frontier" phase of land expansion—cropland expansion rather than yield gains account for most increases in food production. And over the past two decades, most countries in the region have not expanded food production more rapidly than population growth rates.

In this paper I review studies of the economic impact of research and extension program investments. I begin with the observation that investment rates and economic performance indicators show that, in general, investment rates for both research and extension have been as high in sub-Saharan Africa as in Asia and Latin America (though the real "prices" of research and extension services are higher in sub-Saharan African countries than in Asia—see Judd and Evenson 1992). Economic performance indicators, on the other hand, show that the agricultural economies of sub-Saharan African countries have not done as well as those of Asian and Latin American countries (Rosegrant, Agcaoili-Sombilla, and Perez 1995). That section is followed with an analytic framework in which to interpret this experience.

Then I review studies of economic impact of research and extension programs in sub-Saharan Africa and compare evidence from sub-Saharan Africa with evidence from other countries. I then review two sub-Saharan Africa studies (for Kenya and Burkina Faso) in more detail for evidence of "management" and gender impacts. The final section gives policy implications and suggestions for further research.

The Conceptual Foundation for Extension Impact

There are two conceptual themes that are relevant to extension impact. The first is AKAP—the awareness-knowledge-adoption-productivity sequence. The second is the growth-gap interrelationships among extension, schooling, and research.

The AKAP Sequence

It is convenient to visualize extension as achieving its ultimate economic impact by providing information and educational or training services to induce the following sequence:

1. farmer awareness (A)
2. farmer knowledge (K) through testing and experimenting
3. farmer adoption (A) of technology or practices
4. changes in farmers' productivity (P)

Robert Evenson is Professor of Economics, Yale University, New Haven, Connecticut, USA.

Changes in farmer behavior will be reflected in quantities of goods produced, in the quantities of inputs used, and in their prices. These, in turn, can be measured as productivity, which is the added value of goods produced from a given set of inputs made possible by the extension activities.

Studies of extension impacts have measured farmer awareness (and sources of awareness), knowledge (and testing of practices), adoption, and productivity. Not all studies have examined all parts of the sequence. Most have shown a statistical relationship between the quantity of extension services made available to farmers and increases in awareness, knowledge, adoption, and productivity.

Although the AKAP sequence has a natural ordering, it is clear that real resources in the form of skills and activities by both extension staff and farmers are required to move along the sequence. Awareness is not knowledge. Knowledge requires awareness, experience, observation, and the critical ability to evaluate data and evidence. Knowledge leads to adoption, but adoption is not productivity. Productivity depends not only on the adoption of technically efficient practices, but of allocatively efficient practices as well. Farmer productivity also depends on the infrastructure of the community and on market institutions.

Extension services have an impact on each part of the sequence. They can be seen as both substitutes for, and complements to, the acquired skills of their clientele farmers. Empirical evidence indicates that they are, on balance, net substitutes for farmers' skills as reflected in farmers' schooling. For example, extension services are typically not the only source of information awareness (table 1). Skilled farmers can seek out information on their own. Farmers with few skills may not do so. Extension information then may have a higher impact on farmers with less schooling. It appears, however, that the awareness-knowledge part of the sequence is where extension services are strong substitutes for farmer schooling. Through organized frequent contact, they "teach" farmers. And this is more than simply informing farmers.[1]

[1] The recognition of the teaching component of extension has been growing in recent years, especially in the T&V system (Benor, Harrison, and Baxter 1984; Swanson and Claar 1984).

Table 1. Sources of awareness of extension recommended practices.

Study	Country	Group or area	Source of awareness (%): Extension staff	T&V contact farmers	Other farmers	Media	Research centers	Private sector
Lionberger and Chang 1970	Taiwan	Shangfung	36	na	51	5	na	na
		Liupao	24	na	50	4	na	na
Evenson 1988	Paraguay	Western regions	21	na	41	8	1	10
Feder, Slade, and Sundaram 1986	India	T&V farmers	44	na	22	16	2	na
		T&V other farmers	13	na	46	20	2	na
		Non-T&V farmers	2	na	46	23	0	na
Bindlish and Evenson 1993	Kenya	T&V farmers	71	7	0	0	0	0
		T&V group farmers	27	3	38	2	6	4
		Non-T&V farmers	24	2	39	1	3	5
Bindlish, Gbetibouo, and Evenson 1993	Burkina Faso	T&V group members	74	na	14	7	na	5
		Non-T&V farmers	36	na	41	11	na	12

The teaching versus informing distinction is also relevant to the newness of the information (i.e., of the recommended practice or other technology) and of the nature of the practice or new technology. When technology is new (as for example, with a recently released variety of rice) and is also simple to evaluate and adopt (where it is a matter of using new seed without altering other practices) information-awareness is relatively easily converted to knowledge and adoption. Farmers with few skills usually adopt such technology with a time lag. When the technological practice is one that is more complex and requires substantial changes in activities and requires capital investment, teaching is required. Repeated messages, clearly stated and followed up by field staff, and often community organization are required to proceed through the AKAP sequence in this case.

Productivity Gaps and Extension

The AKAP sequencing is, as noted above, related to the flow of new technical information and to the existing state of unadopted technology. We can see this interrelationship more clearly in the context of productivity "gaps." Figure 1 shows crop yields (adjusted for fertilizer and other inputs) for five country groupings differing in technology infrastructure. There are four yield levels depicted for each country group:

- A—actual yields
- BP—best practice yields
- BPBI—best practice, best infrastructure-institutions yields
- RP—best practice, best infrastructure, research potential yields

These yield levels in turn define three "gaps."

- *G(P)*. A practices gap between the best practice yield (BP) and actual farmers' yields (A).
- *G(I)*. An infrastructure-institutions gap between the best practice, best institutions yields (BPBI) and best practice yields (BP).
- *G(R)*. A research gap between the research potential yields (RP) and the best practice, best institutions yields (BPBI).

These gaps provide a way to classify the contribution of extension activities and to show how research and extension are linked. A stylized sequence across technology types is depicted. This could also be visualized as a time sequence.

Extension programs are designed to reduce both the practice gap, *G(P)*, and the infrastructure-institutions gap, *G(I)*. Extension

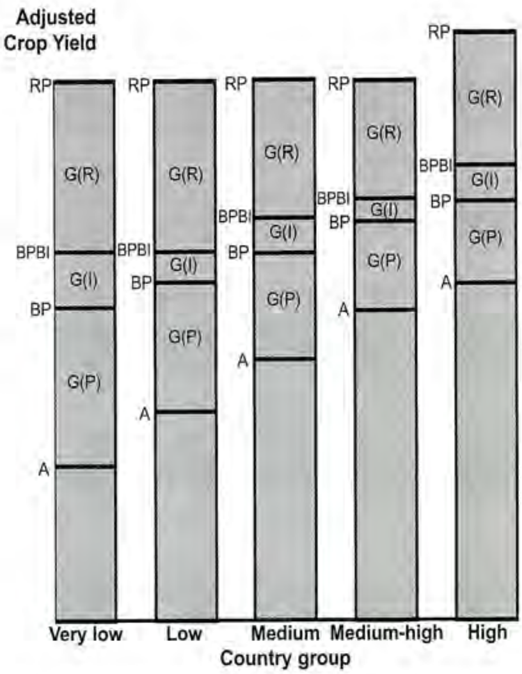

Fig. 1. Yield levels and gaps for country groups ranging from very low to high in technological infrastructure.

programs are not the only activities that reduce these gaps. The provision of market information to farmers and the development of organized farm groups reduce *G(I)*. Information and teaching reduce *G(P)*. Research programs are generally required to reduce *G(R)* by facilitating the importation and local modification of improved technology developed elsewhere. Research programs, in most developing countries, also modify and adapt imported technologies and germplasm.

Two of the gaps are closely linked. When *G(R)* is closed (i.e., when the BPBI yields go up), *G(P)* is opened.[2] (This may happen with *G(I)* also, but to a lesser extent.) Further, it should be noted that the size of the gap is an index of the potential impact of research or extension. As extension succeeds in closing *G(P)*, diminishing returns set in. Successful research opens up new potential by increasing *G(P)*. The relative mix of teaching versus informing is also related to these gaps. When the BPBI yield level has been constant for some time, the *G(P)* gap is closed mostly by teaching. When BPBI is increased, as by "green revolution" rice and wheat varieties, information and testing advice plays a larger role.

The pattern of gaps and yield levels across country groups in figure 1 is intended as a stylized pattern. It is roughly based on experience. For the least developed countries, both *G(I)* and *G(P)* are depicted as large. Many of these traditional economies are producing little new and relevant technology. T. W. Schultz (1964), in his influential book *Transforming Traditional Agriculture*, stated that in traditional agricultural economies where BPBI yields had been constant, farmers were "poor but efficient." In terms of figure 1, he was saying that *G(P)* was actually not very large and that the potential for yield improvement from extension was also low. He effectively said that a rise in BPBI yields was required to create potential for extension to be effective. At that time, few economic studies of extension impact had been completed. The evidence that is now before us indicates that some extension programs in countries with very low technological infrastructure have been effective even where BPBI yields have not risen (see Bindlish and Evenson 1993 and Bindlish, Gbetibouo, and Evenson 1993 for African T&V studies). The evidence also shows that increases in BPBI yields have made extension programs more effective. These issues are critical for policy makers. Because the research gap has proved to be difficult to close in many African countries, it is important to determine what extension program features are required for achieving yield gains from extension in these settings.

Statistical Studies of Extension Impact in sub-Saharan Africa

A number of studies have attempted to measure the impact of public agricultural extension programs in Africa in the following areas:

- farmer knowledge of technology and farm practices
- adoption or use of technology and practices
- farmer productivity and efficiency
- farm output supply and factor demand

[2] This gap-opening phenomenon is the source of new potential gains from extension and explains why extension programs are demanded over long periods. If the BPBI yields remain stagnant in advanced countries, extension has a very limited role to play.

Table 2 provides a summary of *ex post* studies of research programs, extension programs, and combined research-extension program in sub-Saharan African countries. Comments are provided about each study.

Studies assessing extension impact at the individual farm level that utilize a farm-level measure of extension may be affected by two basic estimation problems. The first is the problem of statistical endogeneity in

Table 2. Summary of ex post studies of rate of return (ROR) for African agricultural research and extension.

Study	Location, commodity, and years covered	ROR[a]	Comment
Abidogun 1982	Cocoa, Nigeria	42%	
Makau 1984	Kenya, wheat, 1922–1980	33%	Econometric methods
Evenson 1987	Africa, maize, staple crops	30–40%	Aggregate RORs by region. Econometric.
Karanja 1990	Kenya, maize, 1955–88	40–60%	Econometric. Returns to research only via statistical separation of research from extension; seed distribution effects.
Mazzucato 1991	Kenya, maize, 1978	58–60%	Using Karanja data, finds minimal effect of fertilizer policy on ROR to research
Mazzucato & Ly 1992	Niger, cowpeas, millet, sorghum, 1975–91	< 0%	Nonadoption of varieties released in the study period. Includes extension costs, benefits.
Laker-Ojok 1992	Uganda, sunflower, cowpea, soybean, 1985–91	< 0%	Six-year study period used due to civil unrest in previous 15 years
Boughton & de Frahan 1982	Mali, maize, 1969–91	135%	Introduction of maize into cotton system by CMDT. Returns to TDT system including research, extension, and input distribution.
Ewell 1992	East Africa, potato, 1978–91	91%	Regional network/national agricultural research system collaboration. Returns to research and extension.
Sterns & Bernsten 1992	Cameroon, cowpea, 1979–91 sorghum, 1979–91	3%< 0%	ROR to research and extension
Howard, Chitalu, & Kalonge 1993	Zambia, maize, 1978–1991	84–90%	ROR to research, extension, seed distribution, and additional production inputs
Schwartz, Sterns, & Oehmke 1993	Senegal, cowpea, 1980–85	31–92%	ROR to research-based famine relief includes all aspects of TDT
Sanders 1993	Ghana, maize, 1982–92	74%	Starting date determined by initiation of SAFGRAD program
Smale & Heisey 1994	Malawi, maize, 1957–92	4–7%	Improved research performance since 1985. Focus on breeding program.
Kupfuma 1994	Zimbabwe, maize, 1932–90	43.5%	Research and extension activities of the Dept. of Research and Specialist Services
Aklitu 1930	Ethiopia, extension and adoption	nc	Significant extension impact on adoption of improved practices
Moock 1973	Kenya, productivity	nc	Significant effect of extension on productivity (factor analysis)
Hoberaft 1974	Kenya, maize	nc	Significant effect of extension visits and demonstration on productivity
Moock 1976	Kenya, maize	nc	Extension effects only for farmers with less than 4 years of schooling
Perratown, Jamison, & Orivel 1985	Malawi	nc	Extension visits increase maize yields
Deaton & Benjamin 1988	Côte d'Ivoire, cocoa & coffee	nc	Small extension impact.
Bindlish & Evenson 1993	Kenya	100+	Significant T&V impact
Bindlish, Gbetibouo, & Evenson 1993	Burkina Faso	91%+	Study of recent T&V managed systems

Source: Oehmke and Crawford 1994; Birkhaeuser, Evenson, and Feder 1991.
a\ nc = not calculated.

extension-farmer interactions.[3] Early studies seeking to measure the impact of agricultural extension by identifying the extension variable as some form of extension contact treated this contact as being unrelated to the farmers' actions and characteristics. However, it is likely that one of the characteristics of more productive farmers is the desire to acquire information about changing farm conditions or new technologies. Such farmers may be inclined to attend more demonstration days, read more literature, and seek out extension contact. Analogously, extension agents themselves may also seek out contacts with better farmers who would be good performers even in the absence of extension contacts.

In such a case, the extension-contact variable is endogenous, and the estimates of extension impact on farmers' performance are likely to be biased upward, as some of the better performance credited to extension would in fact be the result of the superior attributes of the group that interacts with extension. The problem of endogeneity can, in principle, be handled econometrically using two-stage procedures or simultaneous equations approaches, but this has been done in only a few of the studies undertaken so far.

The second source of potential bias is the problem of indirect or secondary information flows where knowledge that originates from extension contacts is passed on to other farmers who do not directly interact with extension personnel. The extension of inter-farm communications is substantial, as demonstrated in table 1, which documents farmers' sources of information in several studies. In countries where private farm supply companies are active, sales personnel would be an important source of information, but communication among farmers would still be a significant factor.

Most farmers in areas receiving extension services report that other farmers are the main source of information. Except for the contact farmers in T&V extension areas who are singled out for extension contact by the nature of the program, direct contact with extension personnel is not the major source of information. In the extreme case, information may be diffused instantaneously (to other farmers) from farmers who were informed by extension agents. In such a case, there may be no difference in performance between farmers interacting directly with extension and other farmers, and an estimate of extension impact based on individual extension contacts would erroneously indicate zero extension effects. Generally the presence of inter-farmer communications tends to cause an understatement of extension effects when the approach of defining extension impact by the number of direct contacts is used.

The basic statistical model utilized in the ex post studies shown in table 2 is

$$Z = a + b\text{EXT} + c\text{SCH} + d(\text{EXT}) \mathbf{x} (\text{SCH}) + e\text{RES} + f(\text{EXT}) \mathbf{x} (\text{RES})$$

In this expression, Z may alternatively be a measure of awareness, knowledge, testing activity, adoption, or farm productivity. Extension (EXT), schooling (SCH), research (RES) and other variables are the independent (exogenous) variables that

[3] The term endogeneity is a statistical term. Endogenous variables are chosen or controlled by the units being studied (e.g., farmers). Exogenous variables are not chosen by the units. Exogenous variables can "cause" endogenous variables. Endogenous variables cannot be said to cause other endogenous variables.

determine the endogenous variable, Z. Interaction variables are often included to test for substitution-complementary relationships.

Only studies that incorporate a farmer productivity measure can actually be considered full economic impact studies.[4] In some studies, technology adoption is first analyzed, and then the adoption levels predicted from this stage are included in a second stage productivity regression.

Productivity is sometimes measured as output per unit of input:

$$\text{Output}/(s_1\text{LAND} + s_2\text{FERT}) = a + b\text{EXT} + c\text{SCH, etc.} \quad (1)$$

But in some studies, a production function specification in which inputs are included as independent variables:[5]

$$\text{Output} = a_1 + a_2\text{LAND} + a_3\text{FERT} + b'\text{EXT} + c\text{SCH, etc.} \quad (2)$$

When a production function formulation is used, the interpretation of the coefficient b differs. In equation 1, the coefficient b measures the change in both outputs and inputs caused by a change in extension. In equation 2, the coefficient b' measures the change in output, holding inputs (land, fertilizer, etc.) constant. In either case these estimated coefficients measure the marginal product of extension—the added production due to a one-unit addition to extension services supplied.

The extension variables also typically have a time dimension. Consider figure 2. The adoption of improved practices will typically occur at some rate in the absence of extension services (depending on schooling and infrastructure). Extension both accelerates practice adoption and affects the long-run level of practice adoption. For the least-developed economies, extension, if it is effective, has a strong impact on the level of adoption. For more advanced economies, the extension impact is primarily a speed-up effect.

The time weights built into the extension variable should reflect and even estimate these weights. Most studies find speed-up periods of 3 to 5 years. Recent studies for Kenya (Bindlish and Evenson 1993) and Burkina Faso (Bindlish, Gbetibouo, and Evenson 1993) find significant level effects, implying that extension impacts are long-term.

Knowledge of the timing weights and the marginal product allow the calculation of a marginal product stream ($W_{t+k}MP^*$) over future years associated with an investment in

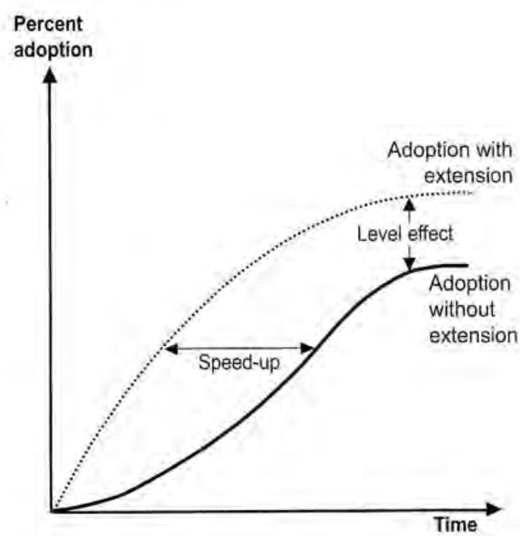

Fig. 2. Extension impacts over time.

[4] The monitoring and evaluation units supported in many extension programs have not generally measured full economic impact.

[5] In equation 1, s_1 and s_2 are factor cost shares. The dependent variable is thus a "total factor productivity" measure. The data observation for estimating the coefficients in equations 1 and 2 may come from farms or from more aggregate data.

time t. This stream can be discounted to find the marginal internal rate of return, r, to the investment:

$$I_t = \sum_k W_{t+k} MP^* / (1+r)^k$$

This rate of return estimate is the measure used to compare both research and extension studies in table 2.

Estimates of Economic Impacts: A Comparative Summary

Table 3 summarizes estimates of the economic impact of agricultural extension from 57 economic studies undertaken in seven African countries (Burkina Faso, Côte d'Ivoire, Botswana, Nigeria, Ethiopia, Kenya, Malawi), seven Asian countries (Bangladesh, Indonesia, Malaysia, Nepal, Philippines, South Korea and Thailand), three Latin American countries (Brazil, Paraguay, Peru), and the USA and Japan. The studies are grouped in several categories. The distribution of the estimates (note that some studies reported more than one estimated impact) is reported by level of statistical significance and by level of rate of return to extension (many studies did not calculate returns, and returns are reported only when the estimated coefficient had a high level of statistical significance).

It should be noted that of the 174 estimated impact coefficients, one-third are reported to be not significant, but few of these were actually negative. This set of studies, however, cannot be said to be fully representative of the regions or types of extension programs. It is likely that a number of studies that found little or no extension

Table 3. Summary of economic studies of extension in 19 countries.

Type	Studies (no.)	Distribution by level of statistical significance: Not significant	Medium significance	High significance	Distribution by returns estimated: Low	Medium	High
Awareness	6	7	2	27	nc	nc	nc
Adoption	9	16	8	17	nc	nc	nc
Productivity							
Farm observation:							
Farm contact	16	21	4	10	2	1	7
Extension supply	9	11	3	21	1	1	12
Aggregate observation	17	4	5	17	2	0	6
All productivity	42	36	13	48	4	2	25
By period							
Before 1980	17	12	3	13	2	2	7
After 1980	40	47	20	79	2	2	18
By region							
Africa (7 countries)	7	2	2	3	1	4	2
Asia (7 countries)	5	0	3	2	3	1	4
Latin America (3 countries)	9	0	2	7	1	1	7
Industrialized (2 countries)	6	0	1	5	1	3	2

Source: Evenson 1996.

Note: For statistical significance, the estimated "t" ratio is <1.5 for not significant, 1.5–2.0 for medium significance, and >2 for high significance. For rates of returns, low is 5–25%, medium is 26–50%, and high is 50% or greater. nc = not calculated.

impact were not reported. I should also note that no monitoring studies conducted by the extension services themselves were included because none calculated economic returns.

Awareness (knowledge) studies. Six studies of the extension impact on awareness and knowledge were undertaken. Three of them (India, Kenya, Burkina Faso—see table 1) examined the impact of T&V management on awareness of recommended practices. These studies found strong evidence that extension does create awareness and knowledge and that the T&V management makes extension more effective in doing so.

Adoption studies. Nine studies of adoption of farm practices were undertaken. All sought to determine the impact of extension in accelerating adoption. This evidence is somewhat less conclusive than the awareness evidence. Most studies found that farm size and farmers' schooling also determined adoption rates. Most studies found evidence for some extension impact on adoption. The T&V studies found that T&V enhanced the extension effect. Two of the studies (Kenya and Burkina Faso—see table 1) linked practice adoption to productivity. Both found that extension accelerated adoption and led to productivity change.

Productivity studies. Forty-two studies reported estimates of extension impacts on farm productivity. Twenty-five utilized farm survey data. Seventeen utilized aggregated data (e.g., district-level data). Sixteen of the twenty-five farm survey studies used a farm-specific extension variable, usually a contact-with-extension variable. As noted earlier, these variables are highly vulnerable to the endogeneity problem. And it is interesting to note that this category of studies actually had the highest proportion of insignificant estimates.

The nine studies that relied on an extension-supply variable, such as the number of extension staff made available in a region or to a group of farms, in contrast, had a high proportion of highly significant estimates. The T&V studies were in this category, and they generally found a T&V management-enhancement effect. These studies used two-stage procedures to predict adoption or membership in T&V groups and found that the extension impact was in general realized through its effect on practice adoption and on T&V group participation.

Most of the 17 studies based on aggregate data included variables measuring research, schooling, and infrastructure in addition to extension variables. Almost all found evidence for an extension impact. The studies that used interaction variables between extension and farmers' schooling generally found a net substitution relationship. Higher levels of farmer schooling reduced the impact of extension (and vice-versa). The studies that examined the research-extension interaction generally did not find a significant interaction except in the U.S. studies.

Estimates by period. There were no differences in the distribution of significant estimates or rates of return by period.

Estimates by country group. I noted earlier that the technological and institutional setting in which extension operates affects its design and its impact. The estimates classified by region show two things: considerable variation, with a substantial range of significance being reported, and a difference between regions, with Latin America being the leading region.

Comparison with research. Table 4 compares rates of return in economic studies of agricultural extension, private-sector agricultural research, and public agricultural research programs. Regional comparison for agricultural research and extension are also provided. These studies reported returns to agricultural extension programs that were similar to returns to both private and public agricultural research.

Further Evidence from Kenya and Burkina Faso

Two studies commissioned by the World Bank provide more detailed evidence for African agricultural extension. The studies were of the Kenya and Burkina Faso systems. Two economic questions were addressed:

1. Were the extension programs affecting farmer productivity?
2. Did the implementation of the T&V management style (in 1982 in Kenya and 1986 in Burkina Faso) make extension more productive?

Two secondary question were gender-related:

1. Did the extension programs serve women farmers well?
2. Did women field extension staff have a differential effect on women and men farmers?

Extension Effectiveness

Both studies addressed the effectiveness question by examining extension effects on:

- farmer awareness of specific technological recommendations
- farmer experiments (in Burkina Faso) with recommended technologies

Table 4. Summary of estimated marginal internal rates of return (EMIRR) for agricultural research.

Commodity	Studies (no.)	EMIRR range (%)					Avg
		ns[a]	10–24	25–49	50–74	75+	EMIRR (%)
Rice	23	0	3	7	12	13	62
Wheat	22	1	4	7	5	7	51
Maize	15	0	3	7	1	6	52
All cereals	69	1	13	23	21	27	55
Soybeans	12	6	1	5	5	6	60
All oilseeds	16	0	1	5	6	9	64
Cotton	5	1	0	2	1	3	56
Sugarcane	6	1	0	4	0	1	39
Legumes	2	0	1	2	1	2	46
Tree crops	5	0	4	1	0	0	26
All agricultural crops	117	45	22	43	30	46	53
All livestock	20	2	7	12	5	6	43
All forestry	15	1	5	5	3	4	44
All applied (aggregate)	53	2	6	33	18	12	49
All pre-tech. science	5	0	0	3	4	1	56
All private R&D (agricultural)	5	0	0	3	3	2	58
All private R&D (nonagricultural)	35	0	0	3	0	5	44
By region							
Africa	7	2	2	1	2	2	40
Asia	5	0	3	1	1	0	30
Latin America	9	0	1	1	3	4	64
Developed countries	6	0	1	0	3	2	63
All agricultural extension	23	1	5	2	7	8	55

a\ Nonsignificant.

- adoption of recommended technologies
- farm productivity

For the Kenya study, seven recommended practices were defined as important recommendations by extension staff. A survey of awareness and adoption was undertaken. The farmer study concluded that the evidence that extension enhanced awareness was weak. There was some evidence that awareness of the more traditional practices relating to timely planting, proper spacing, and the use of improved cultivars was enhanced by extension. The evidence for adoption was stronger. Regions supplied with higher levels of extension services adopted most practices earlier, particularly the traditional technologies. The evidence for adoption of the more modern technologies (plant protection chemicals, stalk borer control, topdressing) was weaker.

For the Burkina Faso study, 12 practices were identified and a survey of farmer awareness, testing, and adoption was undertaken. The study concluded that:

- Participation in T&V extension group increased the probability of *awareness* of several but not all practices.
- Participation in a T&V extension group increased the likelihood of farmer *testing* (or experimentation) of all but one practice (motorized draft).
- Participation in a T&V extension group increased the likelihood of *adoption* of all 12 practices.
- Participation in NGO extension program groups increased the likelihood of *adoption* of several practices.
- Traditional technologies were practices that were developed and used by farmers in other regions.
- Many NGO based programs were specialized for specific crops.

The Kenya study undertook a statistical study of the effect of differences in the provision of field extension staff services on farmer productivity. It concluded that locations with higher levels of T&V-managed extension services did lead to higher farmer productivity. A test for farmer "participation" in T&V groups showed that participation had a positive, but not dominant impact, indicating that the extension service effects were reaching farmers in the community who were not members of formal groups. The implied economic returns to investment were high.

For Burkina Faso, a similar statistical study was undertaken. This study also found that higher levels of extension supply led to increased farmer productivity for individual crops and for all farm production. Membership in farmer extension groups was important in this relationship. There was evidence that other extension (by NGOs) was also effective. There was some evidence for a cumulative impact of T&V programming.

Extension Management Evidence

The Kenya study addressed the management question in two forms. First a comparison between the impact of extension on productivity in 1981–82, before the introduction of T&V management, and in 1989–90, after the introduction of T&V management, was made. Second, extension system characteristics were introduced into the statistical analysis to test for effects of extension impact.

The pre-T&V and post-T&V comparison showed that pre-T&V extension had a statistically significant impact on farmer productivity. However, it was lower than the impact estimated for the post-T&V extension programs. Since several changes other than the introduction of T&V management occurred between 1982 and 1990, one cannot say conclusively that the difference in effectiveness was due to T&V management, but the evidence points strongly in that direction.

The characteristics tests showed that:

- Field extension staff who conduct on-farm research are more productive.
- Field extension staff with more conventional education are more productive.
- Subject-matter specialists with more technical education are more productive.
- Subject-matter specialists who conduct research jointly with agricultural researchers are more productive.
- Higher ratios of supervisors to field staff did not lead to more productivity.

These characteristics are generally consistent with good management principles. They suggest that when high levels of supervision (and layers of supervisors of supervisors) are in place, extension systems are probably unproductive. They also indicate that subject-matter specialists are more useful if they are competent in technical agriculture and have close working relationships with agricultural scientists.

The Burkina Faso study did not have a panel aspect in that earlier data for the same farmers were available. The cumulative effect of T&V extension estimated in the study did support the proposition that extension impacts increased as the system matured.

The evidence from the evaluation of the T&V-managed systems in Africa supports the hypotheses that T&V management enhances extension performance and that extension programs in Africa achieve some long-run "permanent" growth effects. It appears that the African agricultural situation presents powerful challenges to extension programs (although it also appears that some older programs could be considered to be poorly managed and designed). The T&V management structure has two elements that appear to be particularly important. The first is simply the discipline of regular visits with farmers. The second is that explicit role of the subject-matter specialist. This role places the extension staff continuously under pressure to be competent in advisory roles and in the delivery of simple advice to farmers.

The Burkina Faso study is particularly important in that it indicates that there are two contributions made by extension, and these are related to the *G(P)* and *G(I)* gaps depicted in figure 1. One contribution is associated with differences in the staff-farm ratio. Villages supplied with more extension staff time have higher yields. In addition there is an effect of T&V participation (which is partly determined by extension staff ratios and by the T&V program itself). Higher participation is associated with higher yields. This evidence is consistent with the movement form very low to low technological infrastructure levels.

Gender Issues

The Kenya study (Bindlish and Evenson 1993) did address the two gender issues. Thirty-six percent of the sampled farm households were headed by women. Women are very actively involved in farm management and farm work in Kenya. Women farmers had lower proportions of nonfarm income and reported higher proportions of extension advice from extension groups and lower attendance at field days. Women farmers reported lower levels of awareness and adoption of practices requiring financing (fertilizer and chemical use).

The statistical analysis of awareness and adoption of practices revealed little evidence of gender differences. Similarly, for production efficiency, no gender differences were found. (Evenson and Mwabu 1996 gives some evidence for a higher extension impact for women farmers.)

In Burkina Faso, Bindlish, Gbetibouo, and Evenson (1993) found that only 5 percent of the sample households were headed by women. Eighteen percent of all plots surveyed were managed by women. The study showed that female farmers had lower levels of literacy and of extension participation. Female farmers had lower levels of awareness, testing, and adoption of most technological practices. Statistical studies showed that women were actually more likely to adopt organic fertilizer and crop rotation technologies than men but were less likely to adopt improved seed varieties, animal draft, seed treatment, and soil preparation technologies.

Female-managed plots had higher maize and cotton yields and lower millet and sorghum yield than plots managed by men.
More recently, Evenson and Siegel (1995) studied the impact of extension programming on the likelihood that women would actually manage plots in Burkina Faso. They found a large effect. The provision of extension services in the form of T&V groups significantly increased farm participation by women. Extension did this without reducing the productivity of plots managed by women. The effect of female extension staff was to further enhance this effect. Similar effects for NGO extension were found.

Policy Implications

It seems clear that extension programs in most countries of sub-Saharan Africa operate in conditions of low levels of human capital and institutional development. This fits into the very low and low infrastructure-institution levels depicted in figure 1 and contrasts with many systems in Asia where the gaps associated with extension have been closed and where future growth must come from raising best practice yields.

It is possible that research systems in sub-Saharan Africa will raise best practice yields before countries have made the transition to low and medium infrastructure-institution status. But in practice, few countries in sub-Saharan Africa have done so. Most research gains in other parts of the world have been realized in economies that have already achieved low to medium level infrastructural, institutional, and skill levels. We do not yet fully appreciate the factors that initiate a successful closing of this research gap. In some cases this has been induced by the development (often in international agricultural research centers) of genetic resources and methods that increase the research potential yield levels. For some countries in Africa these research potential yield levels may be quite low, so that the research gap is actually quite small. If this is the case, stimulus from above in the form of improvements in science (closing of the science gap) is required to achieve better research performance.

There is some possibility, however, of stimulus from below, i.e., from the extension system, which, if effective, can pressure the research system into more effective action and delivery.

Thus it would appear that in Africa there are two important potential contributions by agricultural extension systems. First, there may be a large extension gap with a significant scope for a permanent reduction that has a long-term permanent growth component. Second, there is some possibility that extension can galvanize the research programs in the area to be more effective.

What are the growth contributions of extension? Consider the general staffing effect. With the level of expenditures in Burkina Faso (roughly 1% of the value of product), this component is estimated to add *0.3 percentage point* to the growth rate in agricultural production. A very high rate of return to investment is being realized on this investment. This staffing effect is also observed in Kenya and in several other studies (e.g., Birkhaeuser, Evenson, and Feder 1991) and represents the regular contribution of extension programs through educational impacts. The second component is actually larger though not necessarily easy to achieve. Yields of crops in Burkina Faso appear to be 20 to 30 percent higher (the actual estimate is 29%) in villages with full T&V participation than in those not reached by the program (controlling for other factors).

After the first 4 years of the program, some 30 percent of the farmers in the random national sample had achieved these gains. It would probably be reasonable to expect 75 percent coverage after 6 years. If this were achieved, agricultural production might be 21 percent (75% **x** 29%) higher than at the beginning of the period.

This contribution has very significant economic value. It could provide 10 years of "breathing room" to enable African countries to reform their research systems so as to achieve the growth potential that has been attained in Asia. But it must be noted that it will be realized only with well-disciplined, well-managed, and competent extension programs. Prior programs have not been able to mine this source of growth. Contemporary T&V programs appear to have been able to do so in some African countries.

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Agricultural Extension in Benin: Village Laboratories and Their Role in the Sasakawa Global 2000 Project

G. Belloncle

Recently I returned from a trip to Benin (the third in 3 years) where I was impressed by progress of six village laboratories followed by Bernardin Gléhouénou, an SG 2000 student doing an applied anthropology thesis under my supervision.

To underline the originality of the experience in Benin, I need to explain that it represents the outcome of an approach that, spread over 30 years, has put me at loggerheads with proponents of all extension systems, including T&V. I have experienced disappointment and conflicts with agronomists in charge of extension in three Sahelian countries where I worked for 20 years: Senegal, Niger, and Mali. Two major events deeply scarred my vision of extension methods, and they also explain my not-easy-to-control passion (and sometimes aggressiveness) whenever I talk about extension problems.

The first event occurred in 1968 in the Zinder region of Niger. I was attending a technical training session organized by the district agricultural officer who was repeating for the umpteenth time his list of simple agricultural themes—seed treatment with a pesticide (for millet and peanut), row planting, economical use of a compound fertilizer (65 kg/ha), and weeding with a cultivator. Then a farmer stood up and spoke, "We know everything you have been saying to us and we've tried them all. But when the soil is dead, your poison [pesticide] and even your powder [fertilizer] do not give anything. A white man arrived 3 years ago and asked for a piece of land, and we gave him the most tired one. He surrounded it with barbed wire, and a young instructor arrived with a complete set of animal traction and started working as recommended by the white man. Today, this field produces hundreds of sheaves of millet where we used to harvest not 10. If you know the secret of this field, let us know. If you don't know, stop boring us."

This field was nothing but a IRAT research substation where researchers were testing innovations that were successful at their research station. The most significant innova-tion was correcting phosphorus deficiency by a single application of 500 kg/ha of phosphate rock (which is a local resource in Niger). The test was able to show, *after 3 years* (the time needed for solubilization), spectacular effects that were boosted by an additional application of 100 kg/ha of urea on cereals.

My visit to this research substation was illuminating. I realized that scientists' files held major technical innovations that could solve the most dramatic problem faced by Niger's farmers—the continuous decrease of soil fertility.

Guy Belloncle is Professor of Rural Sociology, Université François Rabelais, Tours, France.

Based on that experience, I thought, with naiveté, that all agricultural development projects proposed in Niger would rely on research experience. Unfortunately it never happened, neither in the Dosso Project financed by the World Bank in 1980 nor in the Niamey Project financed by USAID. This could not be due to ignorance, because I was in touch with those responsible for the projects and in front of whom I developed my argument on the basis of IRAT reports. Each time, I heard the same objection "You are surely right, and one day we must come to your technical proposals, but farmers are not yet at that level. They must digest simple recommendations first before moving to more sophisticated ones." I was witnessing a tragic misunderstanding: on one side, farmers who, after years of unfruitful trials, abandon simple improved techniques forever, and on the other side, technical staff not proposing a single complex innovation because farmers have not adopted the simple ones.

Ten years later in Mali, I found myself in a similar situation. We had given young (20- to 30-years old), neo-literate farmers some scientific knowledge in agriculture during a training cycle. With the technical support of IRAT farming system personnel, the training program was supposed to set up a model farm managed by those young farmers who would implement all innovations proposed by research. But we had not reckoned with the opposition of the village development project manager. I was summoned by his supervisor who stopped me from coming back to the village for two main reasons: "You criticize the technical themes popularized by Operation Peanut in front of farmers; that's inadmissible" and "you teach the farmers things even our extensionists do not know. Thus you shame them."

One can understand that after that double rejection, I was rather discouraged. However an invitation to present a paper at a colloquium on research, extension, and development, organized by the World Bank and Caisse Française de Développement in Yamoussokro, Côte d'Ivoire, was, it seemed to me, an opportunity to convince some decision-makers to implement—even on a small scale—the new philosophy and the new methodology I was proposing. The paper was a big success. It was translated into English and published by the World Bank in *Agricultural Extension in Africa* (Belloncle 1989). Still I received neither a phone call nor a fax saying "Your ideas are interesting. Let's work together."

In 1992, a chance to implement the thesis and methods developed over 20 years occurred thanks to Sasakawa Global 2000 in Benin and the arrival of Bernardin Gléhouénou in Tours to prepare a thesis. The proposal I made to Bernardin was to conduct his thesis as real social engineering. We would choose a number of village laboratories in which we would discuss with farmers the possibility of trying the most outstanding innovation proposed by agronomic research, wherever it came from. Still the agreement of Marcel Galiba, the project director, and Chris Dowswell, the project supervisor, was needed. Reading two documents written by them convinced me that an agreement could be easily reached. In fact, a report made by Chris said that "the increase of population pressure has completely broken the itinerant system of agriculture, which permitted to soil fertility to be restored," and the conclusion was, "the struggle to maintain an increase of food production higher than population growth will be tough" and it would not be possible without a real agricultural revolution.

For his part, Dr. Galiba, after establishing that "continuous cultivation of cereal on the same land is a sad reality in Benin," explained that the final objective of the project was to propose some agronomic practices to stop the continuous degradation of soils.

It was then possible to reach a common ground, and it was quickly found. The village laboratory concept was accepted and it was decided to choose one village laboratory in each department so there would be six for the whole country.

Last, but not least, the funds allocated to Bernardin's research allowed me, as his director of thesis, to make field visits. That explains how I made three trips to Benin at important stages of the proposed methodology. For the details and justification of the methodology refer to Belloncle 1989. That methodology has been strictly applied to the Benin experiment. It has three phases:

- assisted auto-analysis
- assisted auto-programmation
- assisted auto-evaluation

Assisted auto-analysis consists of helping the people in a selected community (in Africa, generally a village or a quarter) to analyze the agricultural problems they face. The process starts with an opening question, "Which changes have occurred in agriculture since the oldest of you started farming?" (a period of more than a half century).

Typically the farmers cite the introduction of export crops, animal traction, and use of fertilizers, and ineluctably the analysis ends (when it does not start) with mention of the shortening or disappearance of fallow and declining soil fertility ("the land is dead" is the expression often used). The six village laboratories in Benin are no exception: Everywhere from the north to the south the problem of land that is losing its fertility has been singled out as the main problem. In one village, a participant summarized the situation, "As my land progressively loses its fruitfulness, my wives are more and more fertile."

The facilitator can introduce a dramatic note by asking the crowd if the children surrounding them will still be living in the village in the future. The meeting then changes to a real psycho-drama that can reach almost unbearable intensity. Afterwards the tension decreases and one or another farmer will ask, "If you know a solution for that problem, do tell us what to do."

Then we go to the second stage of the meeting—one that combines information-negotiation—or to another meeting because the whole process can last a full day. Contractualization (and particularly by-sensitization, which means farmers are not sensitive to their own problems) as we have seen, that's not the case.

The facilitator explains under which conditions land can be continuously cropped without losing its fertility. At the core of his statement, there are of course notions of rotation and fertilization (both mineral and organic).

We then arrive at the climax of the meeting—the moment we propose that the community test a new way of cropping that will allow turning crops around on the same piece of land. For example, in Benin, the rotation proposed to the villages of the south where they have two rainy seasons and therefore two harvests per year, were maize, velvetbean (*Mucuna pruriens*), cotton, and cassava, covering one-half hectare in total. The major question then is who will take the first step, considering that whole community cannot start such a venture all at once.

The question is important, and villages often ask for a delay for reflection. The solution is to designate 10 farmers who, *on behalf of* and with the consent of the whole group, will implement our proposals. We call those farmers "delegates to innovation," and we see a difference between them and pilot farmers or even contact farmers of the T&V system, even if, lately, more and more are also selected with community agreement. The delegates to innovation are invited to a real revolution under real conditions (remember, they are married and have families). That changes their status in the community. They appear as men who have agreed to run a risk on behalf of the community. As a result, they are highly respected by the group.

The second phase of the method is auto-programmation. Once the delegates to innovation are known and the rotations proposed, we have to give them all the technical information they may need to grow each of the crops under the best conditions.

The third phase is more interesting. Auto-evaluation involves a major aspect of the method. Delegates to innovation are mandated by their community and are accountable for furnishing all technical and economic data. For that reason, they must progressively note all useful information.

Ideally, all delegates to innovation would be literate. In Benin about half of the delegates are literate either in French or in their maternal languages. The others have been helped by a literate delegate or a family member.

Let's talk about the results. In July 1995, the date of our third visit, the three places we visited were on their third crop on the same land, and the technical results were so spectacular that villages were enthusiastic and very grateful to SG 2000. The results:

- Farmers harvested 3 t/ha of improved maize where they had been harvesting 0.8 t/ha.
- Velvetbean developed so well that it blocked out speargrass, one of the most vicious weeds in the village.
- Cotton yield reached or exceeded 2 t/ha.

The new variety of cassava produced 12 to 15 t/ha; usually farmers harvest 6 to 7 t/ha. Technically, we were faced with an undeniable success. But we could not rely on simple visual impressions. Thus, element by element and crop by crop, we had to identify the reasons for such a success. Here is where the expression *assisted* auto-evaluation derives its meaning. Unless delegates to innovation are assisted, they overwhelm the audience with data, and are not able to point out the essential. We had to help them by translating the results into the units of measure the farmers use, which are different from village to village. Thus in certain villages the unit of area is the *kantin*, which represents 400 square meters, while a neighboring village uses the *èso*, which represents 2,000 square meters. Obviously if you give the number of cassava baskets you have harvested on a *kantin* or an *èso*, you are better understood by the farmers than if you give the results in tonnes per hectare. In the village of Assrossa where we stayed for 4 days, we conducted an evaluation of auto-evaluation. Everybody agreed that the new way of cultivation constitutes the only solution to their problems (in particular, they consider the velvetbean a miraculous plant), but nobody remembered the amount of produce obtained, the funds spent, or the net profits made. The village farmers said, "The 'new' farmers [an expression for delegates to innovation] gave us a lot of data, and as we are not literate, we forget it all."

We then organized a special session with the 10 delegates to prepare them to deliver the results obtained by suggesting a real staging. The idea was to present for each crop, the best and the worst yield (most of the time, the differences are small). Thus the champion farmers were designated so that the participants could conclude, for example, that if you want to learn how to get the best yield, you should visit Felix; for cotton it is Alfred; for maize, Augustin.

Only the best farmers designated were able to furnish economic data for the crop that performed best performance. At the end, we summed up the net income that should have been achieved by the farmer who had the best results for the four crops. Those data impressed the farmers participating in that special session.

Finally, when talking with the "new" farmers, we wanted to have their opinions of the innovation's diffusion. We found at that time that the extension had started after the first year. In fact—this is essential sociological information—the whole village is organized in a "help group" that works together with each member of the group. At the beginning, all the members of a help group examined the crops and some as early as the second year ask for technical assistance from the delegates to innovation. The delegates have accepted responsibility for helping a number (three to nine) of farmers in their group That way it was not 10 delegates to innovation who were implemented the rotation but over 30 divided in the four quarters of the village, so no one lags behind.

Three years are too short especially when the challenge is nothing less than proving that one can switch to continuous cropping without decreasing soil fertility (and even improving it).But some conclusions can be drawn:

First, concerning the contents of technical messages, I am convinced that persevering in extension in term of simple technical topics is totally wrong. There are no simple solutions for African agriculture, which faces complex problems.

Second, extension will not make any progress by working with isolated persons or by going from door to door. No one should be banned from the agricultural revolution; we have to involve the whole community.

Third, basic extension is expensive and inefficient. We must give farmers access to technical innovations that are forgotten in research files, let them decide which they wish to implement, and verify its usefulness. For that reason, what we need is a highly educated person who is capable of serving as a mediator between research workers on one hand and farmers on the other hand.

Finally, it is obvious that Benin's experience developed because it was conducted by an anthropologist "with dirty hands" and a field agronomist who are real doctors for soil and plants.

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Gender in Research Design: Old Debates and New Issues

Christina H. Gladwin

By all accounts, women provide most of the labor for domestic food production in sub-Saharan Africa. The most conservative estimate of their average labor force participation is 46 percent for sub-Saharan African women and 31 percent for North African women, allowing for interregional and intercultural differences (Gladwin and McMillan 1989, 348; Dixon 1982). High estimates are that women provide up to 80 percent of subsistence food production in the smallholder farming sector (Spring and Wilde 1991; World Bank 1993). "Female farming systems" are still more prevalent than "male farming systems" in sub-Saharan Africa, to use the terminology of Boserup (1970), by now the accepted wisdom.[1] Traditional gender roles in many societies are such that the woman provisions the household with its food, while the man provides cash income (Goheen 1991).

What are less clear cut are the future changes in, and policy implications of, the so-called gender division of labor for national agricultural research programs that must allocate scarce funds and design new agricultural technologies aimed at increasing domestic food production. Debates—some old and some new—still rage about the future of women's farming, and they often get very heated. The gender division of labor is such a hot topic that everyone, from the smallest of the smallholders to presidents of countries, has a strong opinion about it.[2] This necessarily complicates any policy decision that ministers of agriculture may have to make concerning farming. Given the strong and often-conflicting opinions surrounding these debates, I discuss the rationale behind both sides of four debates, so that their policy decisions, although not easier, may be informed ones.

1 Boserup contrasts "female farming" in Africa—in which food production is taken care of by women with little help from men—with "male farming" in India, in which food is produced by men with little help from women. Using data from subsistence societies in 10 African countries, she shows that virtually all rural women in sub-Saharan Africa take part in farm work and that more agricultural work in the family is performed by women than men. The predominance of female farming is not a given, however, but may change over time (Boserup 1970, 16-36).

2 People are not usually ambivalent about what it means to be a man or a woman in their culture, as *gender identities* are learned at an early age and help us define who we are. From these perceptions are generated norms or rules about the gender division of labor (e.g., a good man does *X*; a good woman does *Y*) that are retained as *scripted rules:* taken-for-granted, almost-unconscious cultural rules that tell us how to act appropriately in our own culture (Schank and Abelson 1977). As a result, these are very sensitive issues we are dealing with, which further complicates the policy decision process.

Christina H. Gladwin is Professor, Department of Food and Resource Economics, University of Florida, Gainesville, Florida, USA.

Debate: Can a Turnaround in African Agriculture Occur *Without* Helping Women to Farm?

Many Africanists, noting the increasing gap between growth rates for food production and population—1.7%/yr vs. 2.8%/yr, respectively, from 1965 to 1990 (Saito 1994)—doubt that the smallholder sector can feed the burgeoning urban populations of sub-Saharan Africa. Instead they advocate the increased commercialization of African agriculture through the development of large-scale private farms to replace the smallholder sector with its many women farmers (Cohen 1988; Hart 1982; Hyden 1980, 1983). They claim that commercialization is necessary to get the forces of production moving again. Opposing them are advocates of a "unimodal" strategy of development capable of reaching the vast majority of African smallholders through farming systems research and extension programs and long-term technology transfer (Collinson 1982; Eicher 1982; Johnston 1986, 1991; Norman, Simmons, and Hays 1982). The latter group, while arguing for agricultural policies and programs designed to reach smallholders, usually ignores the fact that constraints facing women smallholders might also be constraints to the desired turnaround. As a result, their recommendations are often *gender-blind* (i.e., they assume the impacts on women to be the same as on men) rather than *gender-neutral* (they affect men and women equally).

The women-in-development (WID) literature, by now too ample to cite properly, has sought to fill in that gap by debating whether a turnaround in African agriculture can occur without helping women to farm. Papers by Gladwin, Staudt, and McMillan (1986) and Gladwin and McMillan (1989) reviewed this extensive literature and concluded that if African women farmers are *not* helped to farm, there *won't be* a turnaround in African agriculture—simply because of the large numbers of women farming and the great extent of their contribution to domestic food production. In short, if women food producers are not reached by policy planners and national research programs, sub-Saharan Africa will be more and more dependent on food imports with their attending balance of payments problems and food crises.

The evidence, however, was not all one-sided. It showed that in the foreseeable future, African women farmers may be displaced from farming by men—just as black farmers in the southeastern United States were displaced by white farmers from the 1950s to the 1970s, and mid-size U.S. farms are now being displaced by larger superfarms (Gladwin and Zulauf 1989). The reasons are threefold. First, the intensification of agricultural production required for a turnaround causes women's participation in farming to decrease relative to men's, according to Boserup (1970). Second, women farmers have already been replaced in many parts of rural Africa because development planners failed to recognize women as semi-autonomous production-consumption units within the larger extended family household, which is characterized by asymmetric power relationships. Despite all the hoopla about WID/GAD[3] issues, development planning

[3] Some authors distinguish WID perspectives from GAD (gender-and-development) perspectives, which are more sensitive to both men's and women's roles and responsibilities within the household than are WID perspectives (Feldstein and Poats 1989). GAD proponents also believe the key problem in gender relationships is women's subordinate status to men. They argue that if development institutions do not have women's equality as an explicit goal, women will not be included in a development strategy.

has failed and still fails to include women. Third, women still lack access to basic agricultural inputs, capital, the market, and the political arena. I briefly review each of these reasons.

First, the intensification of agricultural production required for a turnaround causes women's participation in farming to decrease relative to men's, according to Boserup (1970). She claimed that "female farming" was prevalent in African societies with shifting cultivation (slash-and-burn agriculture), but declines with intensification and is replaced by "male farming" (Boserup 1970, 16–36). Female farming systems predominate in societies with low population densities and an ample land-person ratio, so that families can produce their food with very small inputs of labor and no fertilization but a fallow system. Boserup (1970, 32) argues:

> It is precisely because such labour-extensive farming systems can be used in most of Africa that it is possible for African villagers to leave most of the farming work to women, while the men work very short hours in agriculture, in comparison to male farmers in densely populated regions of subsistence agriculture.

Population pressure, however, causes shortening of the fallow cycle, labor intensification, and the introduction of the plow. The plow, according to Boserup, leads to an increase in male farming systems in part because the plow increases the number of hired laborers, who tend to be male, and in part because it reduces the amount of weeding women do. Cross-cultural research supports the Boserup hypothesis, showing that intensification—either in the form of labor intensification or of capital intensification and/or technological change—increases male farming. Capital intensification increases male farming "to the extent that men monopolize ownership of draft animals and agricultural implements" (Burton and White 1984, 571). Data also show, however, that the decrease in women's farming may be relative rather than absolute; and women may be *pulled into* additional housework, rather than *pushed out* of agriculture, because more time must be spent on weeding, harvesting, marketing, storage, and food processing with the new cereal crops than with the old root crops (Ember 1983).

Second, this trend is exacerbated by the fact that historically, development planning—and technological change—in Africa has displaced women farmers because policy planners failed to recognize the asymmetrical and complex power relationships of men and women within the extended African family household (Tinker 1976). Treating African households as homogeneous, unified, decision-making units that maximize a jointly held utility function obscures the conflicts and complex complementarities that both divide the household and give women semi-autonomy within the household. Evidence of separate interests of household members comes from studies showing husbands and wives lending each other money at rates only slightly less usurious than the prevailing market rate, the payment of wages inside households, wives selling water to husbands in the fields, husbands selling firewood to wives, and both selling animals to each other on festive occasions (Koenig 1980). In each of these exchanges, the best interests of the household may not coincide with those of particular members, so that it makes more sense to model the household as a "collective"—rather than a unitary entity—in which a wife's budget is delinked from her husband's, and wives respond to changes in their husbands' allocation decisions solely according to their own needs (Alderman et al. 1995; Jones 1983).

Farming households in African societies should be characterized as farm firms with overlapping but semi-autonomous production and consumption units within the firm that cooperate with each other but recognize the asymmetric power relations between them. The units are semi-autonomous because they are managed by the household head, wife or wives, or married sons or younger brothers who are associated with the household through pooling arrangements labor, food, or income. In many societies such as that of the Mossi in Burkina Faso, each wife and married son is responsible for cultivation of a private field, has the right to what the field produces, and so can be called "semi-autonomous." (McMillan 1995) The units are overlapping with asymmetric power relations characterizing the relationship because the wives and married sons must also provide labor upon demand to cooperative fields managed by the household head. In other societies without private fields, the husband and wife may jointly cultivate food and cash crops, some of which are women's crops and some of which are men's crops.

Traditional, informal rules and rights usually determine the extent to which household labor is allocated to the collective fields instead of the private fields, the choice of food versus cash crops grown on each type of field, and the distribution of cash income from cash cropping. (Although informal, North (1990) considers these rules to be the important institutions affecting development; but they are subject to change.) With an intervention from the outside, such as a new cash crop or new land resettlement scheme or the sedentarization of a previously nomadic population, these traditional rules are suddenly questioned and subject to negotiation. Starting in colonial times, conflicts developed over which crops were grown, how much of the harvest was surplus, and how cash returns should be shared. Development projects often channeled agricultural inputs and resources to men rather than women, who because they had no clear traditional rights to their husbands' cash income, found their autonomy and incomes decreased with male involvement in farming. Because men had greater control over scarce resources (land, labor, and fertilizer or manure), they had greater production and profit.

As a result, development planning has failed and still fails to include women, which leads to the third reason women farmers may disappear in the future. Study after study reveals that women still lack access to basic agricultural inputs (land, labor, capital or credit, fertilizer or manure, high-yielding seeds, extension training), education, the market, and the political arena (Bukh 1979; Due 1991; Due and Summary 1982; Elabor-Idemudia 1991; Elson 1989; Gladwin, Staudt, and McMillan 1986; Goheen 1991; Guyer 1991; Quisumbing forthcoming; Quisumbing et al. 1995; Saito 1994; Staudt 1988; Tangka, Pray, and Tavernier 1995). This is because the question of *who* gets access to productive inputs is a political question—the result of a power negotiation—and not just an economic question (Bates 1983); and in a power negotiation, women in asymmetric power relationships lose out to men with greater power, status, and prestige.

Given these three factors, it seems clear that women farmers will be displaced as agricultural intensification occurs. There are, however, other factors that slow the absolute decrease in women's farming in many regions, making it extremely uneven across sub-Saharan Africa. Briefly, they include men's off-farm work and out-migration from rural areas, lack of control of animal diseases (trypanosomiasis, rinderpest) that retard the emergence of animal traction and use of the plow, and variations in land resources and agroclimatic constraints across Africa, which mean the intensification process will not occur uniformly (Gladwin and McMillan 1989, 359–63). To these factors is added the constraint suggested by Boserup (1970, 34–5) that the more the work of hoeing is done by women, the more men will resist the introduction of the plow because "men refuse to do work which according to prevailing custom should be done by persons of the other sex." A new spin on this debate is also provided by Paul Starkey of the University of Reading, UK. According to Starkey, as African men get more off-farm work, get more sophisticated with the plow, or get bored with their monopoly over the new capital input, women get to be in control of the plowing. This happens because more sophisticated farmers learn that one person can control the team of animals pulling the plow, and that one person can be a woman.

These mitigating factors mean that the future displacement of women farmers will be extremely uneven across Africa, but it will occur to some extent. The all-important question of *how much* will depend on the degree of access women get to yield-increasing inputs of production. That in turn will affect the speed and intensity with which African agriculture can be turned around, as the displacement of women farmers may slow or stymie the desired turnaround in African agriculture.

Debate: Are Women Farmers as Productive as Men Farmers?

The policy implications of this debate about whether women farmers as productive as men farmers are far reaching and affect even the most straightforward decision such as whether researchers who want to reach women farmers should conduct experiments on early maturing maize varieties or high-yielding maize varieties. If women subsistence farmers are not as productive as men, they might sacrifice yields for early maturing maize varieties that "allow escape from drought, allow late planting or replanting, provide an early crop for the 'hungry' season, allow a crop where rainy seasons are short, or allow early harvest, making possible a second crop" (Pixley 1995, 1). Men farmers, however, might favor the higher-yielding maize varieties.

What do the data say? The raw, unanalyzed data on yields of female-headed households in sub-Saharan Africa,[4] compared with those of male-headed households (including called joint-headed households), usually show that female-headed households with no able-bodied male present are smaller than male-headed households and have less labor available for agricultural production in a very labor-intensive farming system.

[4] In Africa, female-headed households comprise 25% to 35% of rural and urban households and may be *de facto* or *de jure*. A de facto female-headed household is one in which the husband is away for long periods of time, making it necessary for the wife to do the agricultural decision making and support the family, although there may be remittances coming from the husband. A de jure female-headed household is one in which the head is divorced, widowed, or a single parent and must make all decisions and support the family.

Table 1 is an example of such data collected by Due and colleagues in Zambia and Tanzania. With less labor available, female-headed households have smaller crop acreages planted; this results in lower agricultural output and a higher percentage of production devoted to family consumption, leaving less for sale. Average and per capita net incomes are therefore lower. Because female-headed households have less access to credit, they plant different crops than male-headed households and on average, more of their total crop acreage is allocated to food crops. As shown in table 1, compared with male-headed households (JHH), Zambian female-headed households plant a higher percentage of their crop acreage to maize, the major food staple, and the Tanzanian female-headed households plant more to maize, beans, cassava, and other vegetables. Similar data from Kenya were obtained by Tangka, Pray, and Tavernier (1995). On the surface, it looks like female-headed households are not as productive as male-headed households.

An analysis of productive efficiencies, however, requires the proper estimation of a production function that controls for other explanatory variables besides gender, such as in the IFPRI studies of agricultural productivity (Quisumbing forthcoming;

Table 1. Comparison of joint-headed (JHH) and female-headed (FHH) farm households in Zambia and Tanzania studies.

	Zambia, 1982		Tanzania, 1984		Zambia, 1986	
	JHH	FHH	JHH	FHH	JHH	FHH
Sample size (no.)	**95**	**17**	**118**	**32**	**97**	**27**
Mean						
Age of household head (yrs)	42	44	49	43	41	43
Family size (no.)	7.4	4.5**	na	na	na	na
Adult equivalents[a] (no.)	4.1	2.3*	na	na	3.5	1.7***
Crops area (acres)	11.5	4.9*	2.7	1.4	6.8	3.0**
Maize	7.6	3.8*	1.7	0.8	5.4	2.4**
Beans	0.3	0.2	0.1	0.1	0	0
Groundnuts	0.9	0.3**	0	0	1.0	0.5
Cotton	1.2	0.2*	0	0	0	0
Sunflower	0.9	0.3	0	0	0.2	0
Others	0.6	0.1	0.9	0.5	0.2	0.1
Total value[b]						
Crop production	K 1,201	K 368**	T Sh 5,683	T Sh 3,440	K 4,358	K 1,778**
Crop sales	K 763	K 139**	T Sh 1,166	T Sh 329	K 2,904	K 522**
Livestock sales	K 193	K 35*	na	na	na	na
Farm expenses	K 324	K 85	na	na	K 68	K 3.0**
Off-farm income and gifts	K 216	K 230	na	na	na	na
Net cash income[b]	K 848	K 319	T Sh 3,659	T Sh 200*	K 2,836	K 1,775
Families visited by extension agents (%)	57	29	40	28	60	19**
Crops consumed (%)	38	64	87	96	35	74

Source: Due and Gladwin 1991 based on Due and White 1986 (Zambia 1982); Mollel 1986 (Tanzania 1984); Sikapande 1988 (Zambia 1986).

a\ Adults available for farming: adult males and females equal 1.0, children aged 8–11 equal 0.3, and children aged 12–17 equal 0.5 adults.

b\ K = kwacha; T Sh = Tanzanian shilling.

Significant differences between means: * significant at $p \leq 0.1$; ** significant at $p \leq 0.05$; *** Significant at $p \leq 0.001$; na = not available.

Tangka, Pray, and Tavernier 1995; Alderman et al. 1995). When the analysis is completed, i.e., when researchers estimate a production function that controls for other explanatory variables besides gender such as input levels (e.g., land, labor, capital, extension advice, and education), most studies show that male and female farmers are equally efficient as farm managers (Bindlish and Evenson 1993; Moock 1976; Saito 1994).[5] When these other explanatory variables are held constant while an independent gender variable is allowed to vary in a multiple regression analysis, researchers usually find that the independent gender variable, expressed either as a dummy variable or intercept shifter, is insignificant (Quisumbing forthcoming). This means that gender differences per se do not explain productivity differences between men and women farmers, but gender disparities and women's lack of access to the basic yield-increasing inputs of production result in their lower yields. Quisumbing concludes that the policy solution in this case is to give women greater access to yield-increasing inputs and that addressing gender disparities in input use could be an untapped source of productivity gains for the country as a whole.

More recent work by Udry (1994) and Alderman et al. (1995) reinforce these conclusions. Alderman et al. (1995, 5) compared the productivity on *plots* controlled by men with that of plots controlled by women (including both women household heads and married women) from a sample of 150 households in six villages in three agroclimatic zones of Burkina Faso over 4 years, for a total of 4,655 plots. Their preliminary results show that plots controlled by women are farmed much less intensively and have lower yields than similar plots simultaneously planted to the *same* crop but controlled by men in the same household (Alderman et al. 1995, 10). On average, yields are about 18 percent lower on women's plots than on similar men's plots simultaneously planted to the same crop within the same household. For sorghum, the decrease is 40 percent, and for vegetable crops, it is 20 percent (Alderman et al. 1995, 13).

Does their finding of large gender differences in yield imply that women are less efficient cultivators than men? No, they go on to show that the yield differences reflect differences in the intensity with which inputs are applied on men's and women's plots. They show that plots controlled by women receive much less male labor per hectare as well as much less labor by children and unpaid exchange labor. More female labor is devoted to women's plots, but the difference is not significant. Much more fertilizer—in fact, virtually all of it—is concentrated on plots controlled by men. When Alderman et al. (1995, 20) include these explanatory variables in the production function, the coefficient on gender is now insignificant except for sorghum production. What this means is that "the gender yield differential is caused by the difference in the intensity with which measured inputs of labor, manure, and fertilizer are applied on

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[5] A typical form of Cobb-Douglas production function would be estimated by ordinary least squares by taking logarithms on both sides:

$$\ln Y = a_0 + a_1 \ln L + a_2 \ln T + b \ln E + c\,\mathrm{EXT} + d\,\mathrm{Gender} + e,$$

where Y is output, L is labor input (hired or family), and T is a vector of land, capital, and other inputs, E is educational attainment, EXT is an index of extension services, Gender is the gender of the household head or farm manager, and e is the error term. The coefficient that indicates gender differences here is d, an intercept shifter (Quisumbing forthcoming).

plots controlled by men and women rather than by *differences in the efficiency with which these inputs are used*" by men and women (Alderman et al. 1995, 22).

They conclude that household output could be increased 10 to 20 percent by reallocating the inputs (e.g., moving some fertilizer) from plots controlled by men to plots controlled by women. This estimate agrees with the 22 percent increase found by Saito (1994) in their simulation of the gains from increasing women's input levels to men's input levels on maize, beans, and cowpea plots in Kenya, but it is higher than the 7 to 9 percent yield increases estimated by Moock (1976) also with Kenya data. Quisumbing (forthcoming) cautions, however, that these simulation results need to be interpreted with caution, since they do not reveal *how* levels of inputs may be raised and also assume constant elasticities, i.e., they presuppose that changing the levels of one input does not change the elasticities with respect to other inputs.

The moral of the story? If women were given the same resources as men and had the same access to yield-increasing inputs of land, labor, capital, and education as men have, then the smallholder agricultural sector would see significant increases in agricultural productivity. African countries that address these gender disparities in input use and remove these barriers to women's productivity would increase their agricultural productivity in the aggregate.

Debate: Have Structural Adjustment Programs Improved Women Farmers' Access to Yield-Increasing Inputs?

As Elson (1989, 60) points out, adjustment means change, and change means costs as well as benefits, and losers as well as winners. Who were the winners and losers of the restructuring that occurred all over sub-Saharan Africa in the 1980s? The macroeconomists claimed that structural adjustment programs would improve women farmers' situations because the needed macro-level reforms were *gender-neutral* (O'Brien 1991; World Bank 1994). Women farmers would benefit from structural adjustment programs because previously they were adversely affected by distorted prices (e.g., artificially low food prices, overvalued exchange rates, low interest rates, high wages (Timmer, Falcon, and Pearson 1983), lack of incentives, market failures, and the development bias against agriculture symbolized by parastatal marketing boards that implicitly taxed farmers (Lele and Christiansen 1989). It is important, they said, not to confuse the process of economic reform with the economic crisis and related distortions that discriminated against women and led to their low status (Sahn and Haddad 1991). Women farmers would benefit, they said, when these kinds of discriminatory policies against agriculture were removed and the market rather than the ministry of agriculture was allowed to set the price for agricultural produce and inputs. When price distortions were removed and food prices allowed to increase, women farmers would benefit.

In addition, many observers claimed that rural women were (and still are) adversely affected by structural adjustment programs much less than were urban women and children, the vulnerable group whose purchasing power was cut back drastically when food prices rose in response to the devaluations and subsequent inflationary spirals (Cornia, Jolly, and Stewart 1987). According to these experts, structural adjustment programs—called neo-liberalist policies in Latin America—created an urban underclass in the 1980s (Gonzalez de la Rocha 1992).

Not so, claim many authors in *Structural Adjustment and African Women Farmers* (Gladwin 1991a), because many rural women, especially those in women-headed households, are *net buyers* and not net sellers of food, and so they suffer when food prices rise (Elabor-Idemudia 1991; Due 1991; Due and Gladwin 1991; Meena 1991; Hyden and Peters 1991). Peters in the Hyden and Peters (1991) debate estimates that 40 to 50 percent of households in Tanzania and western Kenya depend on purchased food to a significant extent, and Peters and Herrera (1989) claim that less than 15 percent of Malawi's smallholders are fully self-sufficient in maize production. Lele (1990, 16) characterizes Malawi's agriculture as having a "dualism-within-dualism" structure, that is, the small-farm sector is distinct from the large-estate sector, and smallholders are split into two groups—a minority who have a farm size large enough "to produce a marketable surplus and capable of taking risks and a preponderant majority experiencing stagnation or near economic paralysis." In contrast to Hyden's (1980, 1983) claim that African peasants are "uncaptured" and able to withdraw into autarky, these authors posit that many African women farmers do not produce enough food to be self-sufficient, and so they and their children are hurt when food prices rise Kennedy 1992).

In addition, women producers suffer when the increase in product prices does not match the increase in input prices as a result of devaluation and inflation. Meena's (1991) study of the Mwanza region, Tanzania, showed that food crops controlled by women such as vegetables, fruits, peas, and beans did not get the necessary cash inputs (fertilizers and insecticides) due to their increased prices and women's lack of cash. Furthermore, women food producers were forced to spend more of their time on men's cash crops (e.g., cotton in Mwanza) and had to de-emphasize their own production of vegetables and fruits because of increased producer prices for cash (export) crops. Meena (1991, 175) concludes:

> Price is thus an ineffective instrument to motivate agricultural producers in increasing production, if (1) there is a mismatch between increases in prices of necessary farm inputs and increases in producer prices, or if (2) there is no mechanism to ensure that the surplus which is accrued from the increased producer price benefits all the producers, including women. A price increase of cash crops whose income is not controlled by women cannot motivate women farmers who have nothing to gain from these increases.

Can women gain from food price increases? Guyer (1991) describes a group of Yoruba women who did gain from structural adjustment programs when they started farming to raise cash crops. These entrepreneurial Yoruba women were encouraged to start their own farms by the higher producer prices resulting from the Nigerian ban on all imported food as part of its structural adjustment program. But the question remains: Are they the exceptions that prove the rule?

Most results on the short-term impact of structural adjustment programs on women farmers showed that their ability to respond to improved price incentives and trade liberalization mandated by structural adjustment programs was limited for women subsistence producers (Mehra 1991). As shown above, women lacked access to the basic inputs of production that men farmers had a right to—land (Goheen 1991), credit, and fertilizer (Gladwin 1991b, 1992), even their own labor (Due 1991)—as well as, in many societies, the right to grow export crops (Lele 1990). Given the structural adjustment programs' greater emphasis on tradables, men who grew export or cash crops tended to appropriate more of these basic inputs from the women who grew food crops, making the latter's job to feed the family more difficult and their opportunities to generate a marketable surplus even rarer (Mehra 1991; Meena 1991). Because structural adjustment programs failed to give explicit consideration to gender inequities in access to inputs and resources, women's access was not improved by structural adjustment programs but often worsened.

New issues in this "old" 1980s debate about the impacts of structural adjustment programs on rural women come from at least two sources. First is the new "spin" on making adjustment more humane or allowing African countries to adjust more slowly and "with a human face" (Cornia, Jolly, and Stewart 1987; O'Brien 1991, 35–7; World Bank 1990), as the USA was itself allowed to do during the 1980s by its G7 partners (Gladwin 1992 quoting Paul Volcker on *McNeal-Lehrer News Hour*, June 22, 1992). Questions remain, however, as to whether slower, more humane adjustment programs are any less painful and any more capable of producing tangible results (Cornia, Jolly, and Stewart 1987; World Bank 1990).

Another perspective to this debate comes from recent micro-level, longer-term, longitudinal case studies that look at women's *quality of life over the long term* as the important dependent variable to be explained. These researchers use anthropological fieldwork techniques, live in the local community for a time, and ask farmers whether they are better off or worse off after structural adjustment programs than before. Haugerud (1994) reports that in western Kenya, over half the farmers she interviewed in 1980 and again in 1994 reported they believed there were better off in 1994. These data support the results of a longitudinal study of Orma sedentarized pastoralists who produce meat but do not consume it. Using data from 1980 and 1987, Ensminger (1991) shows that the rise in Kenyan meat prices during the 1980s meant greater incomes and improved education, nutrition, health, and political power for Orma women. These results are also supported by my longitudinal study of 50 rural families in a village in southern Mexico, which showed that in spite of Mexico's economic crisis of the 1980s—dubbed "the lost decade" there—and recurrent devaluations of the *peso*, quality of life and personal earnings have improved for the vast majority of rural women over the last 20 years (Gladwin and Thompson 1995).

It should be noted, however, that these studies, because they are based on historical data, beg the question of whether these women would have been even better off if structural adjustment—and the lost decade—had not occurred at all. But at the least, they provide examples of local economies in which women producers adjust to, and eventually benefit from, the restructuring of the macroeconomy.

Debate: Should Input Subsidies Be Targeted at Women Farmers?

The WID literature unanimously recommends giving women farmers more access to yield-increasing inputs of production (land, labor, capital or credit, fertilizer, manure, high-yielding varieties of seeds, extension advice, and education) to increase both their productivity and sub-Saharan Africa's aggregate food supply. Yet women farmers still lack access to yield-increasing inputs, thanks in part to "the lost decade of the 1980s." What should be done? How can it be done? What are the ideal policy solutions—what Timmer, Falcon, and Pearson (1983) call "the answers"—as well as the "non-answers" to this particularly vexing policy problem?[6] My answer to this policy problem is to recommend that input subsidies in general and fertilizer subsidies in particular, removed in the late 1980s in Malawi and Cameroon at the urging of both USAID and the World Bank,[7] be restored but targeted *only* at women food producers.

Most food policy analysts, however, recommend entirely eliminating input subsidies and particularly fertilizer subsidies because they are a common technique used to increase the profitability of intensive agriculture while keeping food prices artificially low (Timmer, Falcon, and Pearson 1983, 288). Their argument is that only when total fertilizer use is low and the ratio of incremental grain yield to fertilizer application is high can such subsidies be cost-effective, relative to higher output prices or greater food imports. Timmer, Falcon, and Pearson (1983, 288) state:

> Fertilizer subsidies can also speed the adoption of modern varieties. As fertilizer use becomes much more widespread, however, the costs of the program rise dramatically. The production impact per unit of fertilizer subsidy drops because of declining marginal response rates, and because few nonusers of fertilizer remain to be converted to users.

This argument also applies to subsidized credit and irrigation water, with the result that, according to Timmer, Falcon, and Pearson (1983, 288):

> All subsidies tend to distort the intensity of use of inputs from their economically optimal levels, and significant waste is a result. Since not all inputs can be equally subsidized, output price increases will have a greater impact on productivity than will input subsidies, especially in the long run.

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6 Timmer, Falcon, and Pearson (1983) clearly articulate the real and honest dilemmas policy makers face with respect to basic food policy decisions. The most important of these also affects women farmers who are both producers and consumers of food, so that it is worthwhile to repeat it here. "Policies that significantly improve production incentives for farmers often result in reduced food intake for many poor consumers. Broad strategies designed to keep food cheap for these poor consumers have negative production consequences and macro-economic ramifications that can stifle the economic development process" (Timmer, Falcon, and Pearson 1983, 283).

7 In Malawi, USAID negotiated a 1985 Economic Policy Reform Program (EPRP) with two reforms (subsidy removal and substitution of high analysis fertilizers for low analysis fertilizers) in return for $15 million to be disbursed over 3 years (USAID 1990). After initially cutting the subsidy from 29% to 17%, in 1987/88 the government refused to cut the subsidy further, claiming that transportation cost increases, the infusion of Mozambique refugees, and lagging maize production required an increase in subsidy to moderate fertilizer price increases. USAID then canceled the EPRP without releasing $5 million. In 1988 when I did fieldwork in Malawi, the price of fertilizer had increased 50% although the subsidy was still at 24% of delivered cost.

Cameroon started a Fertilizer Subsector Removal Program in 1988, when the subsidy was cut from 65% to 45%, decreasing government expenditures from CFA 6 billion to CFA 2.4 billion. It was projected that the subsidy would decrease to 30% in 1989, 10% in 1990, and zero in 1991. Because it takes a while for fertilizer to filter down to the farmer, however, fertilizer price increases had not yet occurred in December 1989, when I did fieldwork in Cameroon.

I accept this argument when applied to all African farmers except women food producers. For them, input subsidies—particularly fertilizer subsidies—make good economic sense (Gladwin 1991b, 1992). Why? First, African women farmers use hardly any fertilizer. What little data we have *disaggregated by gender* show this. Table 2 from 501 households in Malawi in 1987/88 shows that female-headed households use significantly less fertilizer (34.4 kg vs. 51.3 kg/ha for male-headed households) and have smaller farms than male-headed households. Data I collected from 36 households in anglophone and francophone Cameroon in 1989 agree: average fertilizer use is 52 kg/ha, still lower on maize (30 kg/ha), because two-thirds of the anglophone women farmers use no fertilizer at all. In comparison with the groups for whom Timmer, Falcon, and Pearson (1983) recommend a removal of fertilizer subsidies, African women farmers do not over-fertilize but under-fertilize; yet land is getting scarcer, and fertilizer is a substitute for land.

Second, the main reason women do not use chemical fertilizer is their lack of cash, capital, or credit to acquire it, not their belief in organic fertilizers or a fear of dependency on chemical fertilizers. Both of the latter criteria were included in a decision "tree" model of men's and women's decisions to use both organic and chemical fertilizer, or either of them, or neither of them, on maize in Malawi and Cameroon (Gladwin 1989; 1991b, 199–203). Of the 75 cases of farmers used to test the model, 17 farmers (12 of them women) eliminated both organic and chemical fertilizers due to lack of cash or credit; only five farmers did not use chemicals because of the risk that their land would become dependent on chemical fertilizer. And while more than half (44) of the farmers believed organic fertilizer was needed on maize *in addition to chemical fertilizers*, almost half (20) of them did not use it due to their lack of animals and cash to provide the manure or compost.

Unfortunately, decision-tree models, though rich in information about all the decision criteria individuals say they process while making a decision are usually tested with small samples during personal interviews. Fortunately, statistical tests on larger gender-disaggregated data sets provide similar results about some of the constraints to fertilizer usage that individuals identify during the personal interviews. Data in table 3 show results of an ordinary least squares (OLSQ) regression on the quantity of fertilizer per hectare used by 498 men- and women-headed households in Malawi in

Table 2. Differences between male-headed and female-headed households, Blantyre, Lilongwe, and Kasungu Districts, Malawi, 1986/87.

	Male-headed	Female-headed	t value	prob.
Farmers (no.)	349	152	–	–
Total fertilizer (kg)	72.41	30.24	5.18	0.0001
Fertilizer use (kg/ha)	51.28	34.41	2.29	0.011
Landholding (ha)	1.33	0.80	7.84	0.0001

Source: Malawi Rapid Fertilizer Survey, 1987.

Table 3. Regression on quantity of fertilizer per hectare, Blantyre, Lilongwe, and Kasungu, Malawi, 1986/87.

Independent variables	B	t	*p*-value
Intercept	100.97	12.37	0.0001
AREA	–0.19	–5.25	0.0001
CURCLUB1	36.33	4.50	0.0001
NOCASH	–85.99	–12.33	0.0001
GENDER	0.73	0.11	0.91
CMANURE	21.25	2.45	0.0146

Source: Malawi Rapid Fertilizer Survey, 1987.
Notes: N 498; F 57.79; R^2 0.369; Signif F 0.0001.

1986/87. Regression results show that the independent variables of membership in a credit club (CURCLUB1) and use of manure or compost (CMANURE) significantly increase the quantity of fertilizer per hectare applied ($p = 0.0001$ and 0.01). Variables of farm size (AREA) and lack of cash (NOCASH) significantly decrease the quantity of fertilizer per hectare applied ($p = 0.0001$). The amount of land is linked positively with the total amount of fertilizer applied, but linked negatively with fertilizer per hectare. The smaller the area cultivated, the more fertilizer is poured on; this is partly the result of fertilizer being an indivisible input of 50-kilogram bags at that time. Note that all variables except gender are highly significant. Just as in the productivity studies cited above, *gender per se* has no *direct* effect on fertilizer use—although women household heads apply less fertilizer than men heads, gender does not matter when one holds constant access to credit and cash. It is the access to cash and credit that *explains* fertilizer use; and without access to credit or cash, women apply less fertilizer than men—and get lower yields and incomes as a result.

This result is the same no matter whether OLSQ regression analysis is used or a more sophisticated probit analysis or tobit analysis is used (see table 4, which is based on 526 observations from the same data set, the 1987 Malawi Rapid Fertilizer Survey). Probit analysis was tried because it is a statistical model of qualitative choice (Lukwago 1992, 57–61), but it is inefficient in this case because some information on the dependent variable is thrown away even though it is available. Tobit analysis was also used—and preferred—with these data because the dependent variable in this case (CFERT, total quantity of fertilizer used) is truncated: Many households (301 of 526) report no fertilizer use, but for the rest of the sample households that use fertilizer (225 farmers), the variable is continuous (Lukwago 1992, 61–2, 90–1). The tobit model is a hybrid of probit analysis and the OLSQ method, and it provides the best estimations in a data set with truncated observations. A glance at the R^2-statistic confirms this. Results in table 4 also show that whether the crop fertilized is a man's cash crop also significantly affects fertilizer use: Dummies representing hybrid maize (D2) and tobacco (D7), both men's cash crops, have a positive and significant effect on quantity of fertilizer (CFERT). In contrast, the effects of women's food crops

Table 4. OLSQ, probit, and tobit estimates.[a]

Independent variable	OLSQ CFERT[b]	Probit CFERT (0,1)[b]	Tobit CFERT[b]
Constant	33.8845	0.503200	−2.78535
	(2.24048)	(1.10803)	(0.090651)
Area	24.0156	0.024289	37.0665
	(5.72262)	(2.494890)	(4.86958)
Nocash	−54.5594	−2.69099	−219.531
	(−7.52583)	(−13.3077)	(−11.6760)
Club	56.2560	1.08934	85.8830
	(6.496650)	(4.52466)	(5.936666)
Gender	−1.10575	−0.043482	−6.87823
	(−0.159351)	(−0.211256)	(−0.440354)
Cmanure	19.4016	0.081291	30.7329
	(2.91582)	(2.400874)	(2.23937)
D1	−6.79391	−0.100528	−14.8786
	(−0.508215)	(−2.235183)	(−0.529321)
D2	153.014	1.65513	183.500
	(11.0243)	(3.02978)	(8.27455)
D3	14.8845	5.48532	11.2375
	(0.641276)	(0.110287)	(0.297758)
D4	−6.06980	0.100012	−14.7224
	(−0.677503)	(0.364783)	(−0.708956)
D5	−3.96136	0.306503	4.38976
	(−0.495349)	(1.24633)	(0.258808)
D7	43.9254	0.6133772	43.1417
	(4.25605)	(3.020240)	(2.53062)
Log	−2,904.51	−112.485	−1,401.28
Likelihood R^2	0.562816	0.742997	0.89218
Adj. R^2	0.553256	0.738448	0.88328

Source: Lukwago 1992, table 5.13.
a\ Figures in parentheses are *t*-values.
b\ Dependent variable.

such as local maize (D1), composite maize (D3), groundnuts (D5), and rice (D4) are not significant. This latter result partly explains why women farmers lack cash or capital in Malawi: They produce subsistence not cash crops, so they do not have the cash to buy inputs such as fertilizer or manure.

It doesn't, however, explain why so few women in this sample have credit. Of the 172 women household heads in the sample of 526, only 18 are credit club members; whereas of the 354 men, 112 are credit club members (Lukwago 1992, 68). Do women *not want* credit? If so, what are the implications of this for policy planners who must decide whether to target fertilizer subsidies to women or to expand credit opportunities to them? Many policy planners in Malawi posit that women do not want credit, because they are too poor, too old, or lack a cash crop with which they can repay a fertilizer loan. In fact, the list of constraints is more extensive than that. To answer these questions, I used decision-tree modeling to elicit all the motivations leading to farmers' decisions to get credit for fertilizer, as well as all the constraints blocking them from its use, and tested the models in Malawi and Cameroon (Gladwin 1992, 147–52). Briefly, the results suggest that there are many different constraints to use of credit by women farmers in Africa. In Malawi, the constraints include lack of a local credit club, lack of admission to the club due to age, small size of landholding, and poverty; a woman's marital status (married women's husbands are assumed to get fertilizer for them but don't); a woman's fear of the risk of not being able to repay; and a previous default on the part of the whole club. The fear of not being able to repay is that women don't want to be caught in the situation of having to sell their subsistence crop—in the months when their children are hungry—to repay the fertilizer loan. All these "stage-one" constraints must be passed by a farmer before she or he proceeds to the hard-core stage two of the decision process in which she or he minimizes the cost of acquiring fertilizer (via credit vs. her or his own cash), subject to further cash and risk constraints. In Malawi in 1987, half of the women interviewed rapidly eliminated the credit option in stage one of the decision process without even making it to stage two criteria.

In Cameroon, the constraints are even more binding and are shown in the decision tree in figure 1. Of 36 farmers interviewed, 32 said, "no" to criterion 1, which asked if there was a club in their area that they could join. Only four farmers interviewed in Cameroon reported receiving government (MIDENO) credit: two of them belonged to a MIDENO women's club. In 1989, they had received their first credit for fertilizer.

But there are other options called credit, supplied through the local coffee cooperative (criterion 2, fig. 1), the local credit union (criterion 4), or the indigenous *njangi* or *tontin* systems of saving and lending (criterion 5) to which almost every Cameroonian belongs. Members of the local coffee cooperative sell their harvested coffee in January and receive the next year's fertilizer at the same time, to be applied in February through April to both coffee and maize· the women's crop. This is called "credit," but strictly speaking, it is a cash transaction and the cooperative does not give more fertilizer than can be paid for with last year's coffee. Members of local credit unions save on a monthly basis for a year and borrow against that collateral during the second year, but they cannot borrow more than what they have saved. Members of an *njangi* can build up their collateral to borrow against or put money into a common pot every month to receive 12 times that amount once a year. With these sources of "credit," more men get credit from the coffee cooperative (8 of a total 13), and more women

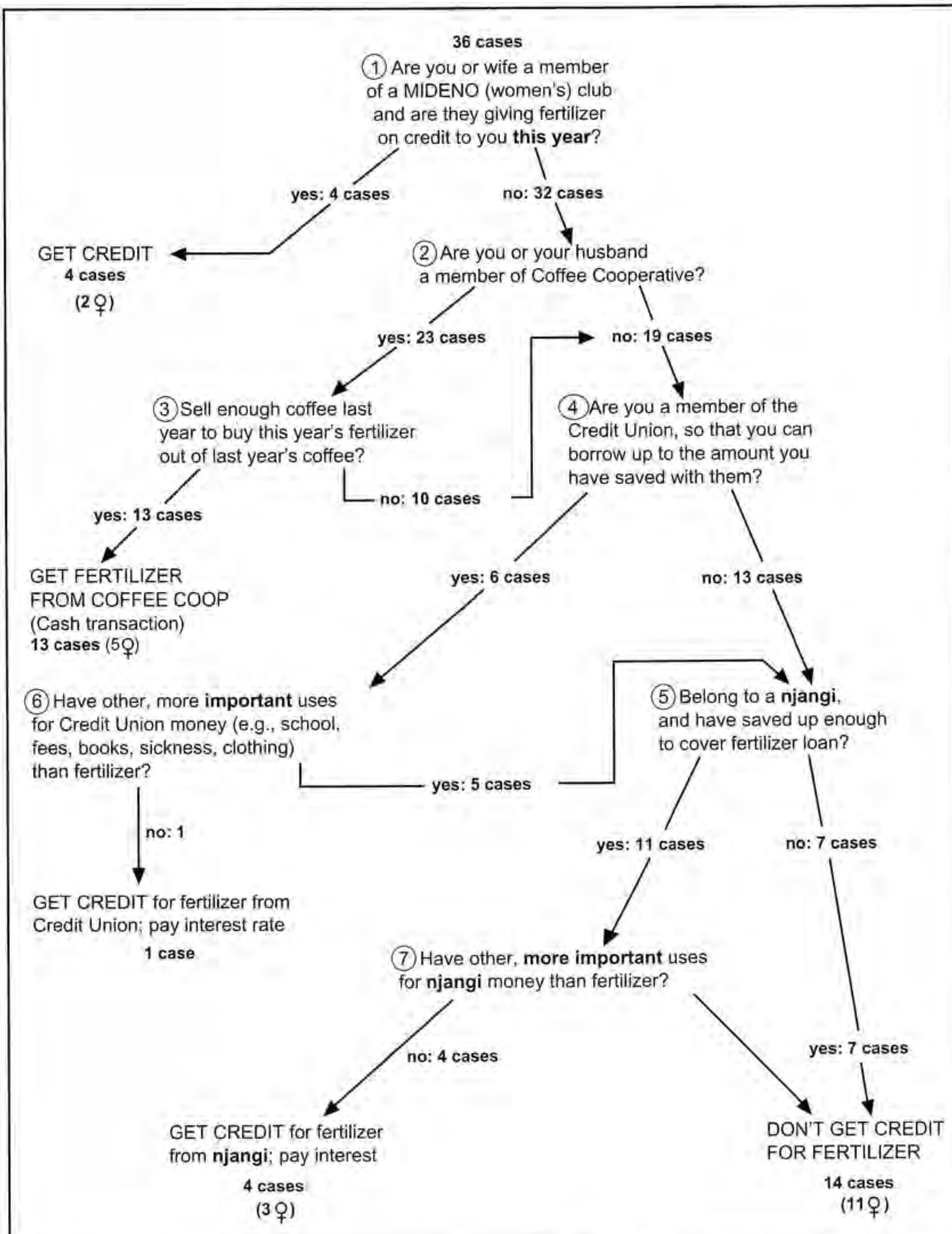

Fig. 1. The Cameroon farmer's decision to get credit for fertilizer (Source: Gladwin 1992, fig. 3, p. 150).

do not get credit (11 of a total 14). This is because women in some regions (the Northwest) are not allowed to raise coffee for sale and so do not have a cash crop to save enough *njangi* money to cover a fertilizer loan.

The result is that, for the policy maker, expanding the credit market is not a policy substitute for targeting fertilizer subsidies at women subsistence food producers. Other policy options that work for men farmers—an increase in producer prices, an expansion of credit—often do not work for women farmers, because they tend to be net buyers of food who suffer when food prices rise, as well as producers of subsistence rather than cash crops. In addition, some women household heads are too old or poor to want credit; they need a grant of a bag of fertilizer per year. How can this be done? Via credit clubs like the MIDENO clubs in Cameroon and the Women's Programme in Malawi. Government can strengthen each women's "revolving credit fund," used to bail out individual defaulting members, by giving the club a small amount when a member supervises the application of subsidized fertilizer on another member's farm. Credit clubs can thus serve not only to expand credit but also to supervise the proper use of subsidized fertilizer bought with cash. Will there be too much leakage of this subsidy from women's food crops to men's cash crops? One answer comes from a Cameroonian who allows his wife to fertilize her maize while he neglects his coffee: "I don't like to be hungry."

There are three new issues in this debate.

1. More agrochemical inputs are a non-answer: Most—but not all—of the advocates for conservation and sustainable agriculture claim that more agrochemical inputs will harm the marginal soils and fragile environments that female-headed households seek a livelihood from (Lele and Stone 1989) and will poison the water supply for villages situated below the hillsides on which women often farm (Paul Nkwei, personal communication). Some viewpoints are more extreme. DAWN (Development Alternatives with Women for a New Era), a grassroots group founded by developing-country women, questioned traditional WID efforts to integrate women into existing development programs. DAWN believes that development strategies striving for overall economic growth and increased agricultural and industrial productivity are inimical to women and their chances of achieving equality with men (World Resources Institute 1994, 44).

Other perspectives are not as extreme. GAD (gender-and-development) advocates claim that *gender-responsive environmental planning* is the answer because women have greater influence than men on natural resource management. Women are the primary collectors of water and fuelwood and have more interaction with local ecosystems (Russo 1995). Rural women have a strong interest in conserving forests and safeguarding the supply of wood products. One survey in Sierra Leone revealed that women could name 31 products that they gathered or made from nearby flora, while men were able to name only 8 (Rocheleau 1991). Farmers also increasingly use trees on farms to enhance food security. Fruits are particularly used as a food for children to tide them over during the pre-harvest period (Scherr 1995, 157). Trees on farms also provide green manure that substitutes for purchased fertilizer or manure. Given women's more frequent interaction with local ecosystems and their concern about the preservation of plant and tree species diversity, it makes sense to integrate environmental and gender-responsive planning at the grassroots level. Uganda, taking advantage of its new decentralization program, has done just that, calling for its local environment committees to identify environmental problems affecting both men and women, to strive for equal representation of women and men on the local committee, to ensure that training events and information are made accessible to women and men in the community, to collect environmental information *disaggregated by sex*, and to mobilize all members of the public to participate in environmental activities (Russo 1995).

Yet here again is a topic about which there is heated debate. According to the Goldman (1995), there is no consensus on the meaning of the term "sustainability" or what we are trying to sustain; and in sub-Saharan Africa, incidents of overuse of technological inputs and resource degradation have been overemphasized. More important causes of unsustainability have been major disease or pest outbreaks and extreme perturbations, both biophysical and social (e.g., climatic and hydrologic events such as droughts, storms, freezes, and floods; tectonic events such as earthquakes and volcanic eruptions; biological events such as pest and disease outbreaks; and socio-economic events such as political upheavals) (Goldman 1995, 297). There is no evidence that land degradation or land use pressure has played a significant role in these.

A corollary is that as land becomes scarcer and in the absence of enough good substitutes for chemical fertilizer, any intensification of agriculture will necessarily mean more use of chemical fertilizer. Fertilizer subsidy removal programs funded in the name of structural adjustment or sustainable agriculture are misguided, counter-productive, and will have the end result of further impoverishing African women farmers.

2. Credit for the poor is a non-answer: In a review of credit programs for smallholders and microenterprises, Adams and Von Pischke (1992) admit that concerns about poor people—particularly women—spur efforts to develop and expand financial systems that deal in small transactions efficiently. Evidence provided by the *Human Development Report* (UNDP 1995) supports this. Only 5 million of the more than 300 million low-income women who run microbusinesses have access to credit from sources other than moneylenders. But Adams and Von Pischke claim debt is not an effective tool for helping most poor people enhance their economic condition, as it exposes them to more risk—the risk of not being able to repay loans.

In addition, "providing financial services to poor people is expensive and building sustainable financial institutions to do this requires patience and a keen eye for costs and risks" (Adams and Von Pischke 1992, 1469). Historically, national savings rates have been relatively low in sub-Saharan Africa, and investment rates have consistently outpaced savings rates, with the savings-investment gap being closed by relatively high levels of external aid (Bresnyan 1995).[8] In the past, the impacts of small-farmer credit programs on the financial infrastructure were virtually ignored; and the programs distorted it by relying almost exclusively on government and donor funds (sometimes PL480 funds),

[8] Savings rates in sub-Saharan Africa averaged 8% of GDP in the late 1980s; and only Kenya and Zimbabwe attained savings rates of near 20% over the period 1987-91.

giving concessionary lines of credit to stimulate targeted lending, subsidizing loans at artificially low interest rates, and giving little attention to savings mobilization at the financial institution (typically a cooperative, agricultural credit bank, NGO, or supervised credit agency). At worst, artificially low interest rates meant that the financial institution could not sustain itself and disappeared; at best, it was sustained only by recapitalization but did not evolve into a true financial intermediary that mobilizes saving deposits as part of its asset base. Adams and Von Pischke (1992, 1465) comment:

> Low interest rate policies distorted the decisions made by financial institutions in two ways. First, the lower the regulated interest rates, the less incentive lenders had to make small loans. Second, these low interest rates on loans also compressed the interest rates paid on deposits, which weakened the incentive to deposit funds.

Targeted loans are even more problematic for the institutions managing them. Most of these programs are transitory and reach only a small percentage of the farmers targeted, who are in turn a minority of the rural population. The more targeted the lending done by lenders, the higher their transaction costs, and the more services and small loans are rationed. The programs are thus unsustainable because they are expensive, collect too little revenue, depend too heavily on outside funding, and often suffer serious default problems. According to Adams and Von Pischke (1992, 1466):

> Most of the "rotating" credit funds set up to support small farmer credit programs failed to make a revolution. They were quickly consumed by loan defaults, by declines in their purchasing power caused by inflation, and by administrative costs that substantially exceeded interest collected on loans.

The failure of these subsidized credit programs can be contrasted with the more positive view of indigenous credit markets at the village level in sub-Saharan Africa expressed by Hill (1986). In the chapter "The Need to be Indebted," Hill (1986, 83–94) points out the benefits from the circulation of village-level credit, and she challenges the view that village moneylenders exploit their fellow citizens through usurious lending practices. Instead, she contends that all villagers know where the money lies in a community, and those who have it are *expected* to put it to use through lending and giving credit that may never be repaid. According to Hill, "debt is timeless" (i.e., unbounded), the lending contract is often nonexistent, and the high interest rates charged by moneylenders are a recognition of the high risks of default. Village moneylenders also take on the guise of true financial intermediaries, receiving savings and deposits for safekeeping and in turn dispensing credit. Hill (1986, 83) says:

> Because rural and tropical communities in which cash circulates are innately inegalitarian, so it is inevitable that the impoverished (in particular) need to borrow and that richer people should wish to put their surplus funds to work. It is mistaken to assume that such borrowing and lending as takes place within a village community necessarily enhances inequality (it may, indeed, reduce it), or is bound to be "bad" for some other reason . . . . Those impoverished people who are too poor to borrow have, as it were, fallen beneath the community and are therefore without hope. Borrowing and lending are necessary for the health of any rural community, "an intrinsic part of the system of production . . . ."

In my judgment, Hill's arguments for indigenous financial institutions such as moneylenders provide one answer to the question posed by Adams and Von Pischke (1992) about how to expand formal financial systems to serve much larger numbers of poor people. Rather than treating village moneylenders as scapegoats, formal financial institutions should be simulating their performance more closely (e.g., charging higher interest rates, providing longer loans on a more informal basis, mobilizing savings and deposits). Similarly, they could pattern themselves after indigenous rotating credit clubs (*njangis* in Cameroon), which function as lending institutions to club members who receive their share of funds early in the year, and as saving institutions to club members who receive funds later in the year. Clearly, both kinds of indigenous institutions are providing financial services of domestic resource mobilization as well as the extension of rural credit, but in not enough volume.

3. *Legal rights and empowerment for women are an answer:* "Women's rights *are* human rights" (Hillary Rodham Clinton, Beijing, September 12, 1995) and must be safeguarded by law. However, they are a necessary but not sufficient condition for including women in a development strategy aimed at increasing smallholder production (Russo 1995; Mehra et al. 1991). Even when substantive efforts are made to reform the legal system to integrate women into the development process, cultural rules regarding the assignment of specific roles, responsibilities, and expectations to women and men may constrain women from becoming actively involved (Feldstein and Poats 1989). Initiatives on the part of women themselves—initiatives that truly empower rural women—are needed to change them.

Conclusion

Can we leave this conference with an action plan to turn around African agriculture by improving the agricultural productivity of women farmers, their households, their communities, and their continent? Can we include women farmers in the planning process, thus empowering them? That is the challenge posed here; and the challenge is yours. To aid in your decision process, I have addressed a series of issues about women farmers that are often subject to hot debate. These include: Can a turnaround in African agriculture occur *without* helping women to farm? Are African women farmers as productive as men farmers? Has the restructuring of the 1980s and early 1990s improved women farmers' access to yield-increasing inputs? Should input subsidies be targeted at women farmers, or can credit expansion be a good policy substitute? These are some of the questions and dilemmas concerning women farmers that the policy maker undoubtedly faces. Both the pros and cons of each debate have been described, so that the decision-making process may be an informed one.

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Gender Considerations in Designing Agricultural Extension Programs

Joyce Endeley and Rosetta Tetebo

Without doubt, public awareness of how gender issues affect the development process has increased in the last two decades. Today, the concern of development experts is to apply the increased level of public gender sensitivity in the design of development programs and projects in disciplines such as agriculture, health, religion, and politics.

Gender consideration in designing programs and projects is a major challenge facing development experts, institutions, and organizations. Among agricultural extension services, few can boast of having a systematic approach for considering gender issues in the design of agricultural extension programs. It is easy to spot token and periodic gestures made by planners or governments in considering gender issues in agricultural extension services when food supply is threatened or there is pressure from funding bodies that have a "women in development" policy.

This paper gives an overview of the concepts "gender" and "gender issues." Such an overview will ease the contextualisation of gender issues in agricultural extension services. Subsequent discussion focuses on major gender issues in agriculture and agricultural extension services; the identification of critical areas for gender consideration in the extension programming process; and illustration of benefits (in qualitative and quantitative terms) due to gender-sensitive agricultural extension services. Examples from Ghana and Cameroon reveal measures that extension services and agents have taken in order to address gender issues in agricultural extension program design, implementation, and evaluation.

Gender and Gender Issues

The word "gender" is a social construct of femininity and masculinity. Gender is an important variable on which societies base their organization and work, as well as distribution of roles and benefits to men and women and boys and girls. The use of "gender" in the distribution of roles and responsibilities is usually culturally specific (UNICEF 1994; Moghadam 1990). However, it is common to find cross-cultural similarities in gender roles and responsibilities in societies that operate under a patriarchal system. For example in male-dominated societies, whether in Africa, Asia, or Europe, women are the dominant actors in the domestic sphere and men dominate the nondomestic sphere. Likewise in agriculture, gender attributes weeding to women and clearing of virgin forest for farming to men. Besides gender division in farming, gender division in crop production exists in many sub-Saharan African countries—women are charged with the production of staple food crops (for both family consumption and

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Joyce Endeley is Head, Women's Studies Programme, University of Buea, Buea, Cameroon, and **Rosetta Tetebo** is Agriculture Director, Women in Agricultural Development, Ministry of Food and Agriculture, Accra, Ghana

marketing), while men produce traditional export crops such as cocoa, coffee, and oil palm (Boserup 1970).

The concept of "gender issues" arises from gender gaps that caused by gender discrimination. The practice of gender discrimination in the social, traditional, cultural, and patriarchal sense not only gives birth to gender gaps and gender inequalities, but it is known to maintain them. Although one cannot assume that all situations of gender gaps, differences, and inequalities lead to gender issues, most do. Gender issues are manifested by the unequal burden of work, allocation of resources, and distribution of benefits and opportunities between men and women in a system. It is a situation where cultural or institutional practices not only enable a particular sex (for this paper, men farmers) to have more privileges and opportunities (than women farmers) but also where the advantages enjoyed by one sex infringe on the development and contributions of the other sex. To the extent that gender discrimination is not only due to customs and traditions but to practices in public institutions and is seen in administrative rules and laws (structural gender inequality), gender issues are major problems of development (UNICEF 1994). Structural gender inequality is commonly practiced in land tenure and financial institutions in Africa. As a result, women are often prohibited by formal legal systems from owning land titles and obtaining credit from financial institutions without the consent of husbands, fathers, or male relatives.

Gender Issues in Agriculture and Extension in Africa

In agriculture, the issues are not only numerous, they also differ in terms of origin (due to structural or traditional gender inequalities), scope (local or national), and magnitude (affect individual or group productivity, access to production resources, participation in agricultural activities, etc.). Regardless of the form, gender issues in agriculture have affected the ability of the agricultural extension service to provide effective and equal services to men and women farmers (Spring 1984; Berger, DeLancey, and Mellencamp 1984; Walker 1987; Swanson and Rassi 1981; Koons 1988; Saito and Spurling 1992). Men farmers enjoy a higher status than women farmers in almost all sectors of agriculture (crops, livestock, agroforestry, and agro-business production). Among farm laborers, managers of agricultural institutions and projects, or beneficiaries of agriculture, men also have higher status than women. Some situations that give rise to important gender issues (directly or indirectly) in the agricultural sector (and have affected planners, institutions, programs, projects, and farmers) include the export-led agricultural development policy of the majority of African governments, the differential access by men and women farmers to agricultural extension services, and the biased attitudes of extension agents toward women farmers.

Export-led Agricultural Development Policy

The pursuit of an export-led agricultural development policy by the majority of African governments has meant the formulation and implementation of agricultural policy, strategy, programs, and projects that favor the production of traditional export crops such as cocoa and coffee and of large ruminants such as cattle, while undermining the production of staple food crops such as cocoyam and cassava and of small animal such as chickens. With men as the dominant actors in the export crop-livestock sector and women in charge of staple food and small animal production, the export-led approach to agricultural development has concentrated almost all agricultural resources and major benefits in the hands of men. Men farmers have better access to production resources such as land, labor, capital, and management; to research institutions and research outputs such as improved seeds, technologies, and techniques; to agricultural extension services and education; to services of other agricultural institutions; and to foreign exchange markets and earnings. Men farmers constitute a greater proportion (sometime all) of the participants in major development projects (Saito and Spurling 1992; Cleaver 1993; Endeley 1992; Bagchee 1994; Teh 1989). The result is that men, and not women, are mainstreamed in the agricultural development process, even though women's contributions in agriculture in terms of labor and food production are indispensable in Africa.

The major effect of women's lesser access (or complete lack of access) to production resources and other agricultural benefits is the continuous marginalization of women's productivity in the entire agricultural sector (Cloud 1985). Women farmers face a much greater challenge in trying to achieve their full potential or utmost productivity in agriculture. Although the visibility of women farmers has improved due to their leading role in staple food production and as agricultural laborers, their reduced ability to earn foreign exchange (even as many staple food crops are becoming tradable in international markets) has relegated them to a secondary position instead of equality to men farmers. Women are regarded as family laborers who assist their kinsmen or husbands, rather than as farmers in their own right.

The biased agricultural policy, existing gender divisions in crop and animal production, and patriarchal attitudes of agricultural planners have resulted in structural gender inequalities in many agricultural institutions (such as the agricultural extension service, financial services, research, and land tenure institutions). The use of "head of household" and "land title" (or ownership of disposal right to land) in the design of agricultural programs and projects and establishing criteria for identifying target participants and beneficiaries characterizes the programming process of agricultural institutions. Thus, most agricultural institutions tend to target farmers who are heads of households or have land titles or disposal rights to land or other collateral such as buildings or export-crop farms. Since these criteria are gender specific in most cultures in Africa, men constitute the majority of participants and beneficiaries of agricultural institutions.

Differential Access to Agricultural Extension Services

Basically, the agricultural extension services reach more men than women farmers. Blumberg (1994) showed that only 7 percent of extension time and resources are devoted to women farmers in Africa. Further marginalizing women farmers in agricultural extension services is the fact that more than 90 percent of agricultural extension staff (including agents) are men (Blumberg 1994; Swanson and Rassi 1981).

A male-dominated agricultural extension service is of very little use to women farmers in areas where tradition and religious practices forbid or restrict contact with the opposite sex (e.g., Muslim societies). Even in areas with no prohibitions on contacts with the opposite sex, male agents are often ineffective in assisting women farmers. Analysts have shown that most male agents (and some female agents) are ill-equipped in terms of their skills, knowledge, and experience to address the problems, concerns, interests, and opportunities of women farmers (Koons 1988; Saito and Spurling 1992).

Women's reduced access to agricultural extension services and the inability of extension agents (particularly male agents) to effectively assist women farmers have had costly effects on women's productivity and the ability of African governments to ensure food for their population. The gap between women farmers and the extension services in Africa explains why women have been slower than men in adopting improved agricultural technology and are less likely to sustain its use. For good reason, women's farming systems continues to be characterized by hoe culture, traditional techniques, and rudimentary marketing technology. Techniques and technologies used by women are nearly obsolete in the face of the agricultural environmental problems that threaten Africa's food security today. Likewise women's reduced access to extension services has meant a gross shortage of appropriate and suitable technologies for women's types of farming systems and production. This is because extension services do not communicate women's concerns and interests to agricultural research institutions for solution. As a result, problems of women farmers hardly appear on the research agendas of agricultural institutions. Rather, agricultural extension services in Africa are often blamed for promoting agricultural practices and technologies that overburden women's labor with little or no benefit to women's productivity or ability to increase personal income or ensure family food needs (Saito and Spurling 1992; Bagchee 1994).

Biased Attitudes of Extension Agents

The influence of traditional beliefs and customs are often noticeable in the manner in which agents (particularly male agents) provide services to women farmers. To the extent that agents believe that women are not important farmers or farmers in their own right, their ability to fully encourage women's participation in extension activities is limited. Generally, agents can hardly detect defects in the strategy they use to assist women farmers, particularly in terms of the scheduled time and location of agricultural extension demonstrations or training activities, using a language that is comprehensible to both men and women farmers, and using appropriate extension methods that can ensure the effective participation of women in group discussions and demonstrations. Not wanting to work with women farmers or relying on men farmers to pass on extension information to women farmers or assuming that women's reticence during discussions in mixed groups of men and women is normal are all outcomes of gender-biased attitudes often inherent in the behavior of agents. Tokenism commonly characterizes extension agents' relationships with women farmers because agents see their work with women more as rendering a favor rather than a responsibility. This is not the case with men farmers whom agents view as "real" farmers and colleagues whose production is of vital interest for family and national development (Berger, DeLancey, and Mellencamp 1984; Koons 1988; Saito and Spurling 1992).

In sum, agricultural extension planners have knowingly and unknowingly encouraged and sustained gender inequalities in agricultural extension institutions in Africa. Gender discriminatory practices have been institutionalized in the programming process without paying adequate attention to extension philosophy, principles, method, and clientele (particularly women). Extension planners and agents have not done a thorough job in analyzing and revealing the impact of certain customs, beliefs, and traditional practices on women's productivity relative to that of men in agriculture.

As a strategic instrument of agricultural development in Africa, the agricultural extension service must be aware of customs, practices, behavior (of agents and farmers), and agricultural policy that create gender inequality and are detrimental to agricultural extension programs. Only then can the agricultural extension service eliminate discriminatory practices that prevent the maximization of women's labor in the agricultural development process.

Designing Extension Programs

Recognizing the negative impact that gender issues have on women's productivity and agricultural development (particularly concerning national food security), many African countries have been paying greater attention to gender issues in agriculture. In the last decade, efforts have been geared toward gender-sensitive planning and execution of projects. Measures that have been implemented by agricultural extension institutions or organizations do not call for gender neutrality in designing and executing extension programs, for such measures would be tantamount to gender blindness. Rather, the majority of measures taken so far have been based on the notion of positive discrimination by gender. Measures by which "gender" and "gender issues" have been considered in the design of extension programs in Africa have been well documented (Saito and Spurling 1992; Bagchee 1994; Walker 1987, 1988; Berger, DeLancey, and Mellencamp 1984). They include:

1. Specific policy statements that commit agricultural extension institutions and institutional resources (staff, funds, time, and equipment) to assist women farmers.
2. A shift in extension focus from large and progressive farmers to small-scale farmers, the majority being women.
3. The adoption of a gender-sensitive approach. Depending on the socio-cultural nature of the society, the approach might mean (a) having a separate extension institution or unit for women farmers in societies where religious and cultural practices restrict or prohibit male-female interaction, e.g., in Muslim societies, (b) having a unit within the parent institution that addresses women's specific and practical needs in home and agricultural spheres (e.g., a women-in-agriculture unit in the ministry of agriculture), and (c) having an integrated unit with men and women agents trained to work with men and women farmers.
4. The implementation of positive discrimination policy where a quota is set (up to 50% in some cases) for male and female participation in agricultural development projects (particularly, in food production projects and smallholder projects).
5. The formulation and utilization of a gender-sensitive recruitment policy with the aim of having a fair balance of male

and female extension staff. The policy usually calls for recruiting more female extension staff. The essence is to ensure that women farmers have greater access to extension service and can reach agents of their choice.

6. The institutionalization and use of gender-disaggregated data collection and analysis methodology in extension program design, implementation, and evaluation. This methodology will provide information on men's and women's participation in, use of, and benefits from extension programs and projects. Agents are able to keep records of their client-agent relationships by gender.
7. The encouragement of extension staff to conduct research on women and agriculture, so that agents become exposed to women's problems, concerns, interests, and aspirations.
8. The periodic organization of gender-sensitization workshops and training programs for field and managerial extension staff. Such training increases the level of gender awareness of all extension staff and improves their abilities to address gender issues affecting extension effectiveness. The goal is to maximize the productivity of men and women farmers.
9. The deliberate involvement of women in the formulation of extension and research activities. That means obtaining information from women farmers about themselves and not through husbands, conducting field experiments on women's own farms, involving women in trials of improved technologies, and addressing women's agricultural problems.

Ghana and Cameroon provide examples of how some agricultural extension programs have attempted to consider gender in design. The case of Ghana reveals measures taken by the Ministry of Food and Agriculture while that of Cameroon illustrates measures taken by an integrated development institution.

Gender Considerations in Extension Programming in Ghana

The term gender consideration in agriculture surfaced in Ghanaian agriculture in 1990–91 when the Crops Research Institute's Grains and Legumes project entered its fourth phase. The project's funder, the Canadian International Development Agency (CIDA), requested that the research agenda have a built-in gender-analysis perspective. This raised an outcry from researchers and other policy makers of the ministries responsible for science and technology and agriculture. Gender considerations were taken to mean women's reproductive issues. This was evident when a series of workshops for which CIDA brought in a Canadian expert to conduct training for researchers, policy makers, and directors of concerned institutions were slighted, and only women and very junior staff members were made to participate. Today the story is very different. The ministers of state and directors who influence policies on research and development are highly motivated and very gender sensitive in planning and executing agricultural programs. Women-specific programs are also highlighted and supported in agricultural and related programs as a result of organized gender-sensitization workshops and the creation of the Women Farmers Extension Division.

Targeting women for overall agricultural messages had never been a deliberate strategy in the Ministry of Food and Agriculture (MOFA) until a holistic and systematic approach was adopted when the National Agricultural Extension System was introduced. The system empowers front-line agricultural extension staff through regular training and by ensuring that staff have the necessary technologies (originating from technical departments in close collaboration with research institutions) to work with farmers. The technical departments of MOFA are then responsible for carrying out gender analysis on the technological messages that are the subject of training for the front-line staff (Al-Hassah 1994; Anokwa and Fiadjoe 1994). The system still operating needs further improvement. Ideally, the involvement of women (both staff and farmers) in the design of technological messages should commence at the conception phase to avoid waste of resources, time, and effort.

In designing a gender-sensitive agricultural extension program, Ghana found it necessary at the outset to look at all crop and livestock enterprises (both male and female) and determine the commodities for which research institutions have developed improved varieties and technologies. The advantages of this comparative analysis are that planners were able to determine which crops and livestock were receiving the most and least attention from research institutions, and which gender is benefiting from research effort, especially as gender division in crop and livestock production and processing exist in Ghana's agricultural system. In addition, this analysis revealed that special consideration must be given to women's reproductive responsibilities and that, in the design and execution of extension activities, extension officers (male or female) must consider women's dual functions (reproduction and production), which takes a toll on their productivity. To ensure that the national extension program focuses on improving the productivity of small-scale farmers, the majority of whom are women, deliberate efforts must be made to target women as beneficiaries of extension programs.

Putting Principles into Practice

These major considerations, particularly the latter (paying attention to small-scale farmers), formed the basis for designing gender-sensitive extension programs in Ghana. In projects already oriented to the smallholder concept, efforts were made to introduce or reinforce the women's component. Reports of projects sponsored by the International Fund for Agricultural Development (IFAD) such as the Smallholder Rehabilitation Development Programme (SRDP) and Smallholder Credit, Input Supply, and Marketing Project had shown that the generalist view that all farmers (male and female) benefit from project effort was not necessarily true (Ministry of Food and Agriculture/IFAD 1992a, 1992b; Ministry of Food and Agriculture 1992). However, with the introduction of the women's component, the project has had significant impact on the lives of farmers. Farmers (men and women) have gained access to water (for both domestic use and animal husbandry), processing equipment for food and oils, and feeder roads to ease marketing of farm produce and reduce head portage. SRDP was able to provide demonstration homes for lessons on home and farm management and other agricultural education. The home management training programs were in the areas of food processing, storage, marketing, and nutrition.

Ghana has also been able to address gender in its agricultural and extension programs through the Department of Women in Agricultural Development (WIAD) of MOFA. WIAD's mandate is to (a) provide advice on and review agricultural policies and their impact on women, (b) conduct adaptive research and develop women-specific demonstration skills of all front-line staff, women's groups, youth groups, and NGOs, and (c) monitor the impact of technologies that have been disseminated. Although WIAD has limited access to resources to fully carry out its mandate, it has, in collaboration with the national agricultural research institutions and universities, been able to develop technological packages in areas such as:

- production, processing, and utilization of farm and backyard crops
- livestock (small ruminants)
- aquaculture development, and wider dissemination of the Chorkor fish smoker
- small-scale processing units and agricultural tools and implements for farming (suitable for both men and women)
- improving household food security and nutrition education

The inclusion of WIAD staff in research teams, e.g., the Inland Valley Consortium of the Crops Research Institute in 1993, has provided for better evaluation of research activities. WIAD is involved in conducting field trials and promoting the adoption and consumption of technological packages. For example WIAD has been instrumental in the promotion of the production and introduction of soybeans in Ghanaian diets. Also, WIAD conducts gender-sensitization training for other agricultural institutions such as the Ghana Grains and Legumes Development project (Halegoah and Okai 1993). Through such training, WIAD tries to secure the participation of women farmers in field trials for various commodities and at different stages in production, processing, marketing, and establishing palatability of improved or new crop varieties, e.g., cooking bananas. In sum, WIAD is playing a leading role in increasing the level of gender awareness among agricultural project planners and field staff of the extension service. It is clear that the measures taken by WIAD and other agricultural institutions will help maximize women farmer's productivity and contributions to agricultural development in Ghana.

Constraints to Women's Productivity Increase

Farm Tools and Equipment. At a recent national meeting to review the agricultural sector, the presidential adviser on governmental affairs commented that Ghana's agriculture will not make meaningful headway into the twentieth century if it still depends on hoes and cutlasses. A major constraint to improving agriculture is the type of tools and equipment that are deployed for farming activities. Compared with women, men farmers have many more improved technologies at their disposal to perform their agricultural activities, e.g., tractors, plows, and animal traction for land preparation, chain saws for felling trees, etc. Beyond the hoe and cutlass, few other land-clearing technologies are used by women. An attempt is being made in the Northern sector of Ghana to introduce animal traction to women and youths through the IFAD-sponsored Smallholder Agricultural Development Project. It is hoped that in the near future institutions such as IITA will develop machinery for harvesting, threshing, and processing of crops that are of interest to women.

Post-Harvest Tools, Equipment, and Agricultural Marketing. Post-harvest management technology for harvesting crops such as cassava, yam, plantain, oil palm, and cocoa is another critical constraint. Women still process most crops (except oil palm and cocoa) utilizing traditional methods. Transportation of produce from farm to market and roadside is mostly done by head portage, a burden for farm and market women.

Engineers and food technologist sensitive to the plight of women food processors are addressing some problems. Examples include the hand-operated machinery for processing fruit and grating cassava developed by IITA, which Sasakawa Africa Association is introducing (through demonstrations) in the country. To date, the machines in operation are for cassava peeling, chipping, grating, pelleting, pressing, and roasting; rice harvesting and threshing; soybean and cowpea harvesting, threshing and milling; oil palm pressing; and groundnut roasting, grinding, and pressing.

Also, research has made efforts to alleviate women's drudgery in the area of fish processing, preservation, and smoking. The introduction of the Chorkor oven, seems to have improved the health of fish smokers. The technology utilizes less wood, and fish processors inhale relatively less smoke than when using the traditional smoking method. Acceptance and use of the Chorkor smoker has spread even beyond the boundaries of Ghana to countries like Cameroon, Tanzania, and Uganda.

In sum, the critical area needing significant agricultural extension attention is post-harvest management of agricultural produce—a domain mainly in the hands of women. There is need to redirect research and funds to unlock some of the bottlenecks associated with post-harvest management of produce so that farmers can reap the maximum benefits from their labor. It is a capital-intensive venture. Massive credit support (unavailable to most women) is required to promote handling, transportation, processing, and storage of the produce. It should be emphasized that there is need to financially support post-harvest management systems, the production of labor-saving technology, and small-to medium-size marketing activities. Teamwork by researchers, extensionists, and marketing agencies in collaboration with women farmers and those involved with processing of agricultural commodities is necessary if women are to make use of improved technologies.

Based on a study of the rice project in Ghana, WIAD concluded that when improved practices are disseminated through female extension staff or extension staff that are gender sensitive, female farmers will adopt and sustain the use of improved practices, provided the technology is affordable (Dakyi 1995). All these efforts will sharply increase the productivity of farmers, particularly women farmers.

Gender Considerations in Extension Programming in Cameroon

In Cameroon the North West Development Authority (MIDENO) was created in 1981 to manage the North West Integrated Rural Development Project. The project comprised three sub-projects: Promotion of Adapted Farming Systems Based on Animal Traction (PAFSAT), Post-harvest Food Loss Reduction Project, and Bafut Village Community Project (MIDENO 1988).

Agricultural extension, training, and adaptive research were elements of all three sub-projects. However, in helping farmers improve their productivity and agricultural production in the North West province, MIDENO was faced with disparity between its extension service (which was male dominated) and women farmers. To bridge this gap, MIDENO had to implement (over several years) the following measures: increase the proportion of female extension agents, improve agents' skills in working with women farmers, recognize women's roles (reproduction and production) in planning extension activities, and give consideration to cultural constraints influencing women's participation in extension activities (Walker 1987). Through these measures, MIDENO has been successful in considering gender in the design of its extension and related activities. The number of female extension agents increased from 9.5 percent prior to the establishment of MIDENO to 18 percent. Expert evaluation of MIDENO's sensitivity to gender issues has shown that its extension agents (both male and female) are gender sensitive and have been able to effectively assist women farmers (Walker 1988; Endeley 1992), and to date MIDENO has been at the forefront in considering gender in designing programs.

Only recently (early 1990s with the new emphasis on the food crop sector and subsequent adoption of the training and visit system of extension) has gender become an important variable in agricultural extension activities and programming at the national level.

Addressing Problems Affecting Women's Agricultural Productivity

The extension and training component of MIDENO is implemented by the Provincial Service of Agriculture. As mentioned earlier, MIDENO's role is that of coordinating and financing sub-projects. Different measures have been taken by these sub-projects to address problems affecting women's agricultural productivity. Currently, MIDENO and PAFSAT's extension activities have slowed considerably because of the restructuring of MIDENO and due to lack of funds.

Land. In the North West province as in other provinces in Cameroon, women mainly have use rights to land. Often the piece of land is far from home and marginal for farming. As a result, women are forced to cultivate several pieces of land because they do not have one piece large enough to grow sufficient food for their family. To improve the fertility of the land and enable women to use available pieces of land for a much longer period, thereby minimizing their search for land, PAFSAT implemented the permanent farming system. The system enables the farmer to use the same piece of land continually. Because soil erosion and infertility are major constraints in agricultural production in the North West, the recommended farming practices call for conservation improvement of soil nutrients. The technological packages include the establishment of contour bunds across slopes, planting of the contour bunds with perennial crops (plantains, pineapples, and coffee), and the use of cow dung and green manure. These steps have solved the problem of shifting cultivation, and farmers can now use a piece of land for much longer periods (PAFSAT 1991).

Labor. In the North West province, men only help women in clearing bush. Other tasks such as planting, weeding, harvesting, and processing of most crops (whether grown by men or women) are performed by women (Koons 1988; Walker 1987). PAFSAT, under its support program for women, has trained women to use oxen. Training for husband

and wife has been compulsory. Also 150 women and 97 women's groups have benefited from this training. Women now use oxen on their farms to plow and make ridges. With this technology (animal traction), women can now work a larger piece of land in a shorter time than when a hoe is used. The technology maximizes women's labor time while alleviating their labor constraints. PAFSAT and MIDENO organize annual seminars for women's groups and farmer leaders. To date, about 2,000 women farmers have participated in these seminars (PAFSAT 1991).

Marketing, Storage, and Processing. MIDENO has been carrying out measures to solve the problems of marketing, storage, and processing under its sub-project known as the Post-harvest Food Loss Reduction Project. The project was sponsored by FAO/UNDP. Just like other MIDENO programs, this project has come to a standstill. However, it has done much to introduce improved drying, storage, and processing techniques for major food crops to farmers. The project has taught women gari processing in Baba 1 and taught the Babungo women's group the technique of producing dehydrated sweet potato chips. The program supplied graters on credit to a local bakery for making sweet potato bread. Farmers were also taught to construct cribs and use 'bamboo box' and actellic powder. According to the annual report 1993/94 of the Provincial Delegation of Agriculture in the North West (MINAGRI 1994), the Baba 1 women's group sold 10 tonnes of gari, and cribs were constructed in Bui and Donga/Mantung divisions. With aid from EZE (German Evangelical Church), PAFSAT constructed 24 multipurpose houses for women's groups. Each house is composed of three rooms—one for storage, one for processing (maize mill), and one for holding meetings. In the house, shelves are made on which potatoes are stored and the heat (smoke) from the maize mill is channeled in such a way to dry the maize, which is also spread out on shelves. Sixteen maize mills costing CFA 1.4 million (about US$2,800) were lent to women's groups (MINAGRI 1994). The mills save time and labor. According to the president of Fangwen Women's group in Ngwatkan-Bali, the maize mill has saved them the energy of covering a distance of about 28 kilometers to Bamenda to grind maize. Even with the decline of PAFSAT's activities due to reduced funding, the women's groups are still using the maize mills and the multipurpose houses. Also, PAFSAT used to collect and sell goods for farmers as a way of recovering loans, but this is not the case today. Currently, PAFSAT provides farmers with marketing information and helps farmers to find markets for their produce.

Credit and Inputs. One of the major problems affecting women's agricultural productivity has been their lack of access to credits and inputs. During the first phase of the MIDENO project, the cooperative FONADER and MIDENO were jointly responsible for providing farmers with credits and inputs (e.g., fertilizer) under the small farmer credit component, implemented by FONADER. With the closure of FONADER and the restructuring of MIDENO, the credit system is no longer functioning. MIDENO is only recovering the funds that had been lent to farmers. In 1993/94, 2,335 packets (1,167 kg) of improved maize were distributed to farmers as inputs under the program for the multiplication of improved maize seeds (MINAGRI 1994). The strike action of the MIDENO unpaid staff brought this program to a halt, hence there was no follow up. PAFSAT on its part gives credits to farmers in the form of oxen, plows, harrows, ridgers, seeds, and fertilizers. So far two groups have completed repayment. Because of the financial hardship, PAFSAT is no longer giving credits. It is now occupied with recovering what was given to farmers (MINAGRI 1994).

Transport. Transporting produce from the farm to the house or to the market is one of the major problems affecting women's agricultural productivity. PAFSAT took this into consideration in designing its animal traction program. Bullock carts were provided to farmers to enable them to transport their produce from the farm to the house. Despite the decline in PAFSAT's activities, most women with the carts and oxen have minimal transport problems (Walker 1987; PAFSAT 1991).

Extension Information. Extension workers usually target only men for messages and hope that the men will pass them on to the women, but this is not usually the case. Sometimes because of religious and cultural barriers, male extension workers cannot work with female farmers hence they have little or no access to extension information. PAFSAT, in an attempt to solve this problem, used the participatory approach and the "dialogue team." The dialogue team is a system where the extension service, adaptive research team, and farmers (both men and women) come together to identify problems and research that needs to be carried out to resolve problems. This method has been successful because it has almost eliminated the top-down approach in extension. Because women are members of the team and their active participation in group discussions is encouraged, women's concerns are addressed by research and extension services. A women's section also operates in PAFSAT, which has been very active in extension activities especially in teaching women how to prepare and eat soybeans. There are 171 village extension workers attached to the Provincial Delegation of Agriculture and 31 specialized village extension workers (MINAGRI 1994). Unfortunately, the data do not show the number of men and women. However, there are few women agents and more are needed.

Impact on Women

Although MIDENO and PAFSAT activities have come to a standstill, the impact of their extension services can be observed in women's practices and productivity.

Attitude. Interviews with two women's groups in Ngwatkan-Bali (Fangwen and Bohja 1) revealed that MIDENO and PAFSAT have helped change women's attitudes. Women have become more receptive to and interested in extension messages. The gap that used to exist between male extension workers and female farmers has almost been bridged. Technologies associated with oxen, oxen-plows, and ridges, which were introduced by PAFSAT, were widely accepted and are being used by women. One exception is the duckfoot (a weeding implement) because it is not suitable for farms with ridges. It is only good for rice farms. The cooking and demonstration department of PAFSAT has also successfully introduced soybeans into the diet of women in the Northwest. Some women said they prepare and eat soybeans in their homes about three times a week.

Practices. Today, most women who have participated in PAFSAT's activities have adopted new farming techniques taught to them by the village extension workers of PAFSAT/MIDENO. On the women's farms, the different methods of conserving soil (contour bunds) and of raising soil fertility (use of cow dung and green manure) could be seen in practice. Interviews with members of the Fangwen women's group revealed that they have accepted the use of oxen and that with them they can work an average of three plots in a day as compared with one plot with a hand hoe. One plot is the equivalent of 600 square meters. Also, almost all the women in the groups interviewed used power grinding equipment rather than manual labor for milling maize, cassava, and beans. The maize mill has helped them save labor and time. Other researchers and analysts such as Koons (1988), Walker (1987), and Tima (1991) have confirmed these findings.

Productivity. There has been an increase in productivity among women, as shown by food crops (table 1), which are mostly cultivated by women. The increased productivity can be associated with the efforts by MIDENO and PAFSAT to reach women and not just men farmers with improved technologies and extension services (MINAGRI 1994).

According to Ma Rose Gana (leader of the Fangwen women's group), before the coming of the oxen project, she used to harvest about five jute bags of maize. With one jute bag being equivalent to 100 kilograms, her harvest was 500 kilograms. But with oxen and the permanent farming system her harvest doubled. This shows that extension services have really had an impact on her productivity. The impact of the extension service has shown that if gender is considered in designing projects and programs, the maximization of productivity can be assured. This has been depicted by the change in attitudes, practices, and the relative increase in the food-crop production of women in areas where MIDENO and PAFSAT operate (Walker 1987, 1988; Endeley 1992; MIDENO 1988, 1989).

Table 1. Food crop production in North West Province, Cameroon, 1993–1994.

	1993		1994	
Crop	Area (000 ha)	Production (000 t)	Area (000 ha)	Production (000 t)
Maize	60.0	168.0	101.0	230.4
Cassava	11.5	92.0	11.6	130.2
Potato	15.0	25.0	16.0	27.3
Beans	21.0	22.7	22.5	26.1
Sw. potato	7.5	9.0	7.8	9.4
Soybeans	0.15	0.2	0.3	0.5

Source: MINAGRI 1994.

Conclusion

As a nonformal educational institution whose clientele is mainly poor, under-resourced adults who depend on the agricultural sector for their livelihoods, the agricultural extension service has no choice than to provide them a meaningful, functional, and productive education. Charged with the additional responsibility of fostering agricultural development to ensure national food security and income for national development, the agricultural extension service in collaboration with other development institutions must maximize productivity among women as well as men farmers. Women farmers constituting an indispensable human resource in Africa's agricultural sector.

Knowing that there are many difficult hurdles to surmount in order to maximize women's productivity, the agricultural extension service must provide services (education programs and technological packages) that empower women farmers. For this to happen, women must participate in extension and research ventures. The maximization of women's productivity involves more than considering gender in the design of agricultural extension programs. Gender-sensitive research, planning, and programs must guarantee that women (a) are aware of their agricultural environment, including factors influencing their productivity and in turn are motivated to want to change unfavorable situations, (b) participate actively in projects designed to improve their productivity—meaning that women should participate in conceiving, making decisions about, implementing, and evaluating projects affecting women farmers, and (c) are involved in controlling projects. Involving women in the project-control mechanism means equal representation of women in project. Equal control can help women farmers gain greater access to resources and improved welfare.

In most documented cases where gender has been considered in the design of programs, agricultural extension services have succeeded in bringing their services closer to women farmers (by increasing the number of female extension agents and by making agents gender sensitive) and improving women farmer's access to available technologies (of which few are suitable to women's farming systems and can address women's agricultural concerns and aspirations in Africa). Where elements of conscientization, active participation, and control have been achieved, women are able to sustain the use of improved technologies and benefits from projects (e.g., the case where women with loans were able to adopt the maize mill and other food-processing technologies and benefit from their management of the multipurpose house project in Cameroon). Unfortunately, documented cases of successful and sustained adoption of technologies have been limited to women's specific projects and not joint projects involving men and women. However, it is doubtful that the result will be different if women and men farmers have equal control over suitable technology, projects, and programs. It is important that women do not remain at the mercy of agents or planners who are reluctant to target women for fear that access to improved and profitable technology will upset the patriarchal order.

Gender-sensitive agricultural extension programming must avoid educating women simply for welfare and nutritional purposes. It should also make women inquisitive and critical thinkers. Rather than continue to render free labor in agriculture to satisfy patriarchal demands, some labor can be used in proper reconstruction of the reality of the population. The maximization of productivity among women farmers requires that extension programs empower women farmers to discover their individual worth and the value of their work and those of others in relation to theirs, to critically analyze extension messages, to question accepted views of the reality, and to become more aware of gender issues affecting their productivity.

Women can no longer be viewed as passive recipients of agricultural extension and research messages. They can create knowledge that is vital for agricultural development (IFPRI 1995). If agricultural planners including researchers consider women in this light they will, together with women in the agricultural sector, solve the major concerns of women farmers, thereby maximizing their productivity as well as national production.

Finally, the inability of this paper to link a particular measure to an outcome in a quantifiable manner (e.g., an increase of X percent of female agents resulted in a Y percent increase in the number of women farmers served by extension or who adopted a particular technology) is due to limited empirical research. Mainly descriptive studies with indicative findings are available. Empirical research studies that can establish relationships between measures taken and outcomes are needed to provide planners with information on how to maximize gender planning.

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Transport and Agricultural Development in sub-Saharan Africa

Jean H. Doyen

Much progress has been made during the 1990s in building broad support for the proposition that agricultural growth is central to economic development and to the alleviation of poverty in Africa. The recent conferences of African ministers of agriculture have undertaken to mobilize their governments to adopt broad-based development strategies centered on agriculture. In developing a consensus on the policies needed to foster agricultural development, the conferences and other policy statements—in particular ones by IFPRI—have stressed the importance of rural infrastructure and transport services. A recent report on poverty reduction in Africa by the World Bank (1995) makes similar points. That report guides the bank's effort on poverty reduction as the overarching goal of its programs in sub-Saharan Africa. Its conclusions are particularly relevant to sizing up the role of transport:

> Poverty in Africa is primarily a rural phenomenon; 70 percent of the poor live in rural areas. Labor intensive agricultural growth is central for poverty reduction.
>
> Governments and donors must find ways to generate considerable increase in the rate of growth and to restructure the pattern of growth toward the poor, in particular the rural poor.
>
> Poverty reduction requires a focus on the rural economy and special attention to opportunities for rural poor to increase their income and to facilitate their access services.

The need to accelerate growth and to sharpen the focus on the rural poor provides a useful framework for understanding how transport policies and programs affect agriculture (table 1).

Table 2 provides an overview of the role of, and current issues related to, the various components of transport systems at the national, regional, and local level as a backdrop for considering transport policies and programs most relevant for agriculture.

The National Policy Agenda

The competitiveness of agricultural products and their access to the regional markets are hampered by the poor organization and performance of the transport industry. In most countries, agricultural commodities and inputs are the single most important component of freight flows in national systems.

Sub-Saharan Africa's participation in world trade has decreased over the last 20 years. Many factors account for the decline. Unsuitable macroeconomic policies rank first. Lagging research and the insufficient capacity of the private sector are also important. A third factor is high logistic costs and poor quality of services. Although sub-Saharan Africa is still grossly underequipped in terms of transport infrastructure, many countries have great difficulty in maintaining

Jean H. Doyen is Chief, Environmentally Sustainable Development Division, Technical Department, Africa Region, World Bank, Washington D.C.

and operating existing systems and facilities. Sectoral policies are the root cause of the poor performance of the transport sector. Now that the basic layers of adjustment measures are taking hold across sub-Saharan Africa, the distortions that affect performance at the sector level are coming to the forefront. Direct state interventions and parastatal monopolies combined with restrictive regulations have sustained high cost structures and have been an obstacle to the introduction of the technological innovations that have revolutionized international transport and logistics over the last 20 years. Reservation of cargo rights, assignment of trucks loads, and public monopoly or controlled access have hobbled the competitiveness of sub-Saharan Africa agriculture through rents and poor services.

High transport costs and poor marketing services eat into farmers incomes in two ways: They add to the cost of inputs, which mostly have to be purchased on international markets, and they reduce what the farmer can be offered for his crop. Maize from Kansas is fully competitive in Dar es Salaam with maize produced in western and central Tanzania. The added costs of protection of national shipping lines was estimated at more than 15 percent of the landed cost in Europe for the banana production of West and Central Africa. Eventually the banana producers from Côte d'Ivoire gained the freedom to contract directly for specialized sea transport to Europe with significant savings and improvements in timeliness and quality. Although agricultural constituencies have a large stake in transport infrastructure and services, they have generally not played a commensurate role in influencing programs and policies related to infrastructure and services.

Farmers' associations and agricultural constituencies have a key role to play in pressing for changes and in hastening the pace of policy reform in the transport sector. This will be critical to ensure that improvements obtained at the level of individual modes, e.g., road rehabilitation and railway restructuring, translate into better and cheaper services to shippers along the whole transport chain. The agenda will of course vary from country to country. The following objectives are likely to be of particular interest to farmers and agricultural constituencies across the region:

Table 1. Transport and agricultural development.

Transformation of agriculture		Transport services		
From	To	National systems	Regional & district	Village & household
Subsistence farming, self-sufficiency, low monetization	Producing for the market, maximize income, savings specialization, trade	••	••	•
Resource-based, low-yield, low input use	Science-based, high yield technologies, reliance on inputs	•	••	••
Limited access to social services	Effective demand for social services and capacity to pay for them	•	•	••
Isolation, low mobility, disempowerment	Mobility, broadened opportunities, participation	•	••	•

Note: • = of general importance. •• = of primary importance

- To build up maintenance capacity and rehabilitate roads. The emphasis should be on initiating or consolidating policy reforms and extending their impact to secondary and feeder roads.
- To improve the environment for the development of competitive road transport services free of restrictive regulations except as related to safety and axle and vehicle weight.
- To foster the development of intermodal services, especially inland penetration of containers and through-services across borders.
- To press for improvements in quality and cost of port services through institutional reform and users' involvement.
- To eliminate compulsory cargo reservation systems and support the reform of shippers' councils to make them primarily answerable to shippers.

A lot is at stake in all these reform. For example, the order of magnitude of avoidable costs and transfers resulting from the cargo reservation practices in place in West and Central Africa was conservatively estimated at US$200 million per annum in 1991. The deepening of sectoral reform and the focus on services to shippers are essential for restoring the competitiveness of agricultural products and uncovering the potential of regional trade. To gain a more effective voice on transport policy and programs, agricultural constituencies will have to organize themselves much better than they are at present in most countries.

Roads, tracks, and the services they support are the most important element of transport

Table 2. Transport systems for agriculture: Role of components and current issues.

Role	Issues
NATIONAL TRANSPORT SYSTEMS	
Ports and maritime transport	
Overseas trade, 100% of inputs and all exports (except horticultural products)	High cost, lack of modal integration, lagging in facilitation and logistics
Railway systems	
10 to 20% of freight flows; potential as regional carriers underutilized	Slow and unreliable, financial weakness, poor organization of through services
Road transport services	
80% of traffic flows; essential to bring inputs and serve markets.	Resilient and entrepreneurial; high cost and low quality (wastage, poor security.)
Trunk highways network	
20% of the roads carry 80% of traffic; generally low standard and poor condition	Lack of capacity to maintain; large backlog of rehabilitation being addressed in half of the countries in need.
RURAL ROADS AND LOCAL TRANSPORT SERVICES	
Secondary and tertiary roads (Regional and district)	
Regional feeder system; linkage with markets and access to urban-based services	Lack of capacity to address maintenance requirements; low utilization limits level of investment.
Community roads	
Linkage to feeder system; communication between villages and from houses to farms; considerable impact on farmers' productivity and quality of life especially for women.	Unclear assignment of responsibility; limited access to intermediate technologies.

systems. They affect all aspects of the rural economy—access to markets, use of inputs and the range of technologies available, productivity (as farmers do a lot of their own transport), and welfare in terms of access to social services and mobility. Two systems can be distinguished: first, trunk road systems, which relate more to the objective of broad-based growth and, second, rural roads and village-level services, which relate more to the focus on poverty. Key parameters defining the two systems are summarized in table 3.

Road Maintenance and Rehabilitation: The Starting Point

The need to make up for the backlog of rehabilitation works accumulated over the last 20 years and to build up maintenance capacity is now clearly understood. In the transport sector, this has become the primary focus of governments and donors. Programs of appropriate scale are under way in about 13 countries and are under preparation in another 10. Countries that have shown serious intent in grappling with the reform needed to set their road sector on a sustainable footing have found adequate support from donors.

The high economic return of large programs now under way, estimated at 25 to 35 percent, illustrates their contribution to growth. The annual benefits from improved maintenance and ongoing rehabilitation are estimated at more than US$1 billion annually. Another way to comprehend the stakes is to consider that roads are the single most important physical asset for most countries; their replacement value is estimated at US$150 billion of which more than a third has been lost to neglect.

The economic impact of road rehabilitation on a specific region and its rural community can be illustrated with an example from Tanzania (World Bank 1994). Twelve kilometers of the Kwa Sadala-Mbera road (Kilimanjaro Region) was rehabilitated in 1992. The road serves 11 village with a total population of 34,000 settled on highly productive land. Four months after the completion of the road, a survey commissioned by USAID showed that the daily average traffic had jumped fivefold (from 59 to 274) and passenger movement 20-fold (66 to 1,300), demonstrating the pent-up demand for personal travel. The impact of road improvement on personal mobility is also illustrated by the 226-kilometer

Table 3. Sub-Saharan Africa (SSA) roads infrastructure: Overview and key parameters.

	Length (000 km)		Traffic	Cost [a] (US$000/km)			Condition 1991 (%)		
	SSA	RSA [b]	(vehicles /day)	Construction	Rehabilitation/ upgrading	Annual maintenance [c]	Good	Fair [d]	Poor [e]
Main networks	535	62							
Paved	135	57	3,000–150	500–200	200–80	3.5–1.5	50	30	20
Unpaved	400	5	300–40	40–60	20–15	1.5–0.8	20	25	55
Rural unpaved	630	233	100–10	20–6	12–6	0.5			
Unclassified tracks	>2,000	na	20–2	5–2	2–0.5	0.3			

a\ Order of magnitude.
b\ Republic of South Africa.
c\ Routine plus average periodic maintenance.
d\ Periodic maintenance overdue.
e\ In need of restoration.

Tunduma-Sumbuwanga road—its rehabilitation led to the organization of regular bus services, five per day, where none had existed for years.

The challenge has been taken, but the problem is by no means over. The coverage has to be broadened; advances have to be consolidated. Several countries, such as Ghana, Tanzania, and Mozambique, are now in their second and third programs. Such programs are sectorwide and provide a coherent framework for organizing donor support. In many ways, they illustrate emerging good practice in donor coordination. Annual commitments are running at about $700 million per annum, i.e., about half of the target set under the Second UN Transport Decade (UNECA 1990). The effort should extend well into the next 10 years and will continue to need the coordinated support of donors. Two considerations will be important in bringing other countries into the drive for road policy reform and rehabilitation.

First, the country-based process for the development of better road policies should be initiated early, even by countries that are not in a position to undertake comprehensive programs because of macroeconomic issues or because of instability. The progress made by Zambia and Sierra Leone, ahead of any major rehabilitation program, illustrate the point.

Second, measures to improve the management of rural roads and build capacity at the regional and district levels should be initiated together with those directed at the trunk network either through separate operations, as in Ghana, or under an integrated approach, as in Tanzania. The pre-requisite for both should be a clear commitment to undertake policy reform.

"Out of Africa—A Smoother Ride" was the title of the full-page article that appeared in *The Economist*, June 10, 1995, reporting on the advances made in setting road management and financing on a sustainable footing by countries participating in the Road Maintenance Initiative (a collaborative program supported by donors and participating countries to develop and implement effective approaches for road-sector management). The RMI program has focused on how to deal with the nexus of weak institutional performance and unreliable and inadequate funding. It proceeded from the premise that the road departments would have to be brought under a framework where they would have to address the needs of their clients, that is, the road users, and have the incentive and the freedom to operate commercially as businesses seeking to maximize value for money (Heggie 1995). The decisive step was to involve the users and help them define what they need, find out how much they are ready to pay, and have a say in what is done with their money. As the reform proceeded in Zambia and Tanzania, the key elements were distilled into what is referred now as the commercialization agenda for roads.

The experience gained with the pilot countries suggests that reforms have to be undertaken in four interdependent areas, the building blocks of sound road management:

1. Creating ownership by involving users, winning support for more funding, establishing accountability, and controlling spending. This is usually achieved through a road board with active representation and de facto control of the private sector (Zambia, Tanzania).
2. Securing adequate and stable funding through a road tariff (over and above the

general fuel tax) channeled directly through a road fund fully dedicated to road maintenance, supervised by the road board and subject to audit.
3. Clarifying responsibilities for trunk and various levels of secondary roads.
4. Strengthening management accountability.

The Road Maintenance Initiative holds important lessons for rural roads (Riverson, Thriscutt, and Gaviria 1991):

- Direct involvement of users through regional road boards (being considered in Tanzania) and district road associations
- Stable funding dedicated to maintenance and upkeep of the existing network rather than to expansion and upgrading
- Clear assignment of responsibilities establishing a framework for programming and accountability.
- Donor support channeled through coherent sector program with facilitation of policy work under a collaborative framework
- Country-driven policy process with the participation of users and stakeholders, moving at its own pace, and not linked through conditionalities with the financing of operational programs

Rural Roads and Transport Services

Programs for improving rural infrastructure and related services need to be expanded with a special focus on the rural poor. This concern is not new; the lack of sustainability of the programs initiated under the drive for integrated rural development in the late 1970s and early 1980s, calls for different approaches. An unpublished World Bank review of past experience (by K. Twumasi) and the emerging lessons from recent programs have improved our understanding of the institutional and policy environment required to achieve more lasting results. They also provide guidance for the design and implementation of rural infrastructure programs. The fundamental point is the need to focus on capacity-building close to the users.

At the onset, it is useful to consider rural road and transport not only from familiar perspective of the planners but from the viewpoint of the rural household. This can be done through an example from the Obengkrom-Bogyampa community in the heart of Ghana's cocoa belt. The community consists of about 2,500 people in 30 settlements covering an area of about 120 square kilometers. The inventory of transport infrastructure is as follows:

Feeder road, classified	27 km
Access roads and tracks (unclassified, motorable dry season)	52 km
Footpath	90 km
Total	169 km

Transport infrastructure expenditures for 1993 were estimated at US$60,000 (not including self-help), i.e., $24 per person, of which three-fourths was provided by the central government through the regional branch of the national feeder road agency for the rehabilitation of the feeder road and one-fourth was collected within the community.

This example underscores the importance of feeder roads, which, at the level of a village network, play the role of a collector. The rehabilitation of the feeder road running through the district led to the re-opening of long-abandoned cocoa farms. In fact this relatively large investment spearheaded the initiative of villagers who undertook complementary work within their reach.

The example also illustrates the relative importance of paths and tracks, which make up more than 80 percent in length of local transport infrastructure and account for a similar proportion of the daily movements of the inhabitants. Their level of serviceability has much significance for the lives and productivity of individual household members, in particular women. Surveys have shown that women bear an overwhelming share, often more than 80 percent, of the transport activities of rural households, mostly by headloading. This activity occupies 20 to 30 hours per week. Lightening up this load and freeing this time is important.

Village-level rural transport interventions are increasingly included in rural infrastructure programs. A World Bank "approach" (Relf forthcoming) provides a starting point for country actions. Overhead and communication costs are likely to be an issue for replicability. This suggests the need to combine such measures with other community development programs. It is clear that the extension service has a role to play, given the relevance for productivity and welfare. Rural transport programs typically serve communities and village associations on a self-selecting basis. They include a combination of the following measures:

- Assessing options for improved services within and without the community, as well as training and advice
- Planning and management of the community network of paths and tracks
- Providing small grants for spot improvements and tools to complement community self-help
- Facilitating access to intermediate means of transport (wheelbarrow, carts, bicycles, etc.) through credit and demonstration

Village-level rural transport is an integral part of rural infrastructure strategies. Building capability in the design and implementation of related interventions will be critical for replicability.

Lessons from Rural Road Programs

Institutional problems were the main cause for the poor outcome of efforts expended on feeder roads in the 1970s and the 1980s. A review carried out in 1991 concluded that "In most countries the policy framework and institutional arrangements needed to support expanded programs and ensure the maintenance of feeder roads has yet to be developed" (Riverson, Thriscutt, and Gaviria 1991). Another type of problem was that promising pilot schemes launched mostly with the involvement of NGOs and bilateral donors could not be replicated and mainstreamed into countrywide programs. The two main reasons were high technical assistance content (often not included in project cost) and inability to address underlying policy issues such as parastatal monopolies (e.g., for borehole drilling) and ineffective and ill-adapted public procurement systems. The latter has been a recurrent issue for the mainstreaming of programs to develop labor-based capacity for road works.

Most of the institutional problems encountered in rural infrastructure derive from the context under which programs were launched, i.e., a highly centralized approach, limited reliance on the private sector, and a disfranchised rural population. This led to management by a central agency and planning based on consultant studies that relied on derivation of economic rates of return with little possibility for participation of regional and district staff, not to speak of the communities concerned. Responsibility for maintenance was not clearly assigned or acknowledged. Although the context has changed dramatically in many countries, it is clear that the broad institutional framework is of particular importance for the sound management of rural infrastructure. Among the reasons for this are the multiplicity of actors involved and the broad spread of such programs.

A more recent review of the World Bank rural infrastructure portfolio shows significant improvement in design: focus on capacity-building, decentralized management, and planning systems founded on community participation (Hallgrimsson forthcoming). The limited coverage (about a dozen countries) and the fact that commitments are not increasing suggest that task managers and country planners are focusing on doing the right thing. The dissemination of emerging good practice will be important in the World Bank, as well as among countries and donors.

Conditions for Sound Rural Road and Transport Programs

Progress toward effective decentralization: Most countries are decentralizing. Often, responsibilities have been transferred, but budgetary control and fiscal resources have remained at the center. Another issue arises from the fact that the scope of the responsibilities that have been decentralized has not been properly assessed and agreed upon. Authority over centrally appointed civil service personnel is blurred. Rural infrastructure programs have to be put squarely in the context of ongoing decentralization, relying on aspects that have progressed well and providing remedies to problem areas. Rural road programs can play a key role in clarifying roles and building capacity by effectively engaging decentralized entities in planning and implementation, thereby giving them legitimacy and providing them with experience.

Commitment to users' and stakeholders' participation: The framework for participation should be built, whenever possible, on existing local institutions. Attention is needed to ensure that the objective of participation is well understood, in particular the implications for planning, budgeting, and local resource mobilization and management. Participation strategies should include specific ways of reaching disadvantaged groups such as women and landless laborers.

Enabling environment for the development and use of local resources and capabilities: The review of World Bank experience by Riverson, Thriscutt, and Gaviria (1991) correctly pointed out that the only way to ensure that the know-how for maintenance is developed is to rely on local resource for improvements and rehabilitation. The goal is to create conditions under which small local road contractors can flourish. This holds implications for program design, i.e., training, simplified forms of contracts, size of contracts, organization of the bidding process, continuity in workload, etc. The most important aspects are, first, the capacity to expedite payments promptly and reliably and, second, the capacity to administer procurement effectively. Central administrations are rarely able to deliver on any of these requirements.

Capacity to effect payment reliably and on time: Prompt and reliable payments require financial planning, a regular flow of funds, and efficient disbursement procedures. In most countries, rural road programs will have to establish mechanisms to overcome the lack of capacity (e.g., a revolving fund fed partly by external sources and setting aside the full value of small contracts up front), while at the same time supporting capacity-building and institutional reform needed to address underlying deficiencies in the longer term. The important point here would be to work within the system and avoid multiplicity of project-based mechanisms.

Delegated contract management: The option of delegated contract management (following the AGETIP[1] model in which a specialized NGO is entrusted with the responsibility for management all the way from the design phase to completion) offers a way to overcome the limitations of public procurement systems. Eventually, if the delegated contract management is adopted as the method of choice, it will be important to develop capacity for delegated management at decentralized levels. The other issue is to ensure that delegated contract management does not diminish participation and ownership. This may be the most serious limitation of the method.

Focus on building local capacity with a sector program approach and long-term commitment: Rural road management is seen by rural communities as a continuing function, not as a one-off undertaking. The fact that earth roads require frequent rehabilitation and that the tasks involved in such rehabilitation are essentially the same as those needed for maintenance also underline the need for continuity and for a network management approach rather than project-based planning dealing with individual sections. The latter may be handled under ad-hoc complementary financing that may be available under social funds mechanisms. The full implementation of the sector program approach will have to be achieved gradually. The important point will be a commitment from all donors to work within existing structures and to avoid relying on institutional enclaves.

Key Elements of Rural Transport Programs

A coherent institutional strategy is needed to:

- Define roles and organize the collaboration among the many actors involved: central, regional, and local governments; community organization; and NGOs
- Establish clear and coherent planning and funding systems for channeling domestic as well as external resources to districts and communities

Identify needed policy and institutional reform and to situate rural road programs within the context of ongoing decentralization processes

The strategy has to be articulated around the needs and the capacity of the districts and the local communities. Its primary focus should be on institutional arrangements for planning and funding. The mechanisms for the transfer and disbursement of funds should be simple and transparent.

Successful programs have relied on a single focal point at the center to deal with advocacy, policy, overall planning and budgeting, and coordination with the main road agency in monitoring, evaluation, and capacity-building. The apex agency should assume no responsibility for local planning and implementation, which should be decentralized.

The second element of strategies for improving rural transport is a program to build the capacity of small rural contractors. This will usually be undertaken in conjunction with broader programs sponsored by the main roads agency for the

[1] Agence pour la Gestion des Travaux d'Intérêt Public.

domestic road construction industry. The promotion of small-scale rural contractors will lead naturally to the reliance on local resources including labor. In order to emphasize the focus on the intensive use of labor, complementary measures will be needed in the following areas: technical specifications, forms of contract, bidding processes, and, most important, training of managerial and supervisory staff.

The third and critical aspect of rural road programs is to make arrangements for timely and reliable funding in the early phase of implementation; this is the lifeblood of the system. The volume of funding is not as important as the fact that all involved should trust that what has been committed can be counted upon. One important source will be road funds. Those established by Tanzania and Zambia allocate a set share of their revenues (20% to 30%) to secondary and rural roads. This aspect will also require innovations by donors to make progress toward the channeling all external funds through a single mechanism.

How to Get Going

Each country will be have to evolve its own strategy and systems. In planning the preparation process, three steps should be considered:

1. Initiate the strategy process following the model of the Road Maintenance Initiative through the establishment of a rural transport committee with involvement of users and stakeholders. The process may add regional committees to incorporate the needs and the issues raised at the region or district level. Donors and NGOs as well as project staff would need to be involved. The committee will oversee the preparation of the institutional strategy and will subsequently steer the implementation of reform and deal with emerging issues.
2. Take stock of good practices from the country's own experience. This would be of particular interest to donors and NGOs and would draw upon their participation. The evaluation framework would be developed by the committee, and the results would feed into the strategy formulation and implementation process.
3. Initiate action as soon as possible on the basis of successful pilot projects. Early action with flexible management is essential to generate interest, mobilize constituencies, and feed the learning process.

The steps outlined above will require consultation, advisory services, workshops, and studies. Related funding requirements will be well above the resources usually available for project preparation. The existing collaborative framework for rural transport, i.e., the Rural Transport and Travel Program, would provide a suitable mechanism for meeting these requirements. The added advantage is that this will foster exchanges and networking.

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The Role of Inputs and Marketing Systems in the Modernization of Agriculture

W. Graeme Donovan

Why Agricultural Growth is Critically Important

Agriculture's most important development benefit is the diffusion, throughout the economy, of lower real prices for farm goods, especially food. When real food prices fall, real wages rise without raising nominal wage levels. Food is the most important wage good. Holding down its real price allows employment to grow, and it increases the competitiveness of all sectors of the economy. But food is not the only agricultural product that is important. We know that raw materials from agriculture dominate the early phase of industrialization,[1] which is, for that reason, really agro-industrialization. Holding real prices for these raw materials steady, or getting them to decline, gives a big boost to such agro-industrialization and therefore to the rural economy as well as the wider economy.

Technology and Marketing

There are two main forces driving these lower real prices for farm goods. The first is technology, and the second is marketing. Improved *technology* allows farmers to receive more income even when real prices of their product are falling because they can produce more for each unit of their land and their labor. Competitive, more efficient *marketing* reduces the price difference between the farmer and the final consumer. In some cases this allows what at first sight seems too good to be true—farmers can receive higher (nominal) prices at the same time consumers pay lower prices. We must keep clearly in mind that, although we often talk about farmers responding to prices, and they do, they are really concerned about income, not price *per se*.

What we're interested in at this workshop is how to get more out of investments in agricultural research. Obviously anything that gives farmers the incentives, and the means, to take up the better technologies emerging from research will "add value" to research investments and will in fact increase their rate of return. When we focus on the role of inputs, in this context, we must acknowledge that the new or improved technologies ride on the back of agricultural inputs such as water, seeds, fertilizers, agricultural chemicals, tools and equipment, livestock feeds, and so on. It is to increase the productivity of these inputs that technology development is undertaken, and especially to increase the productivity of two key inputs, land and labor.

Now, the physical productivity of agricultural inputs is one thing and their financial or economic productivity quite another. Being able to get 5 kilograms of maize from 1

[1] In Kenya, for example, agriculture largely provides the materials and supplies for 12 industry groups which together account for 58% of the gross product of the manufacturing sector.

W. Graeme Donovan is Principal Economist, Agriculture and Environment Operations Division, Eastern Africa Department, World Bank, Washington, D.C.

kilogram of fertilizer is not very interesting to a farmer if the maize is worth EB 5 and the fertilizer costs EB 6. It may not be very interesting, even if the fertilizer costs only E B 3, because the net profit from the fertilizer may not be enough to cover other costs of production or to induce the farmer to take the risk of using the fertilizer in a rainfed environment.

I want to repeat what I said earlier: Farmers are interested in income. And income is affected by the prices of both outputs and inputs, as well as by the physical ratio of output to input. It is the physical ratio that agricultural research focuses on. This physical ratio is squeezed between two pieces of marketing—that for outputs and that for inputs, both of which affect the prices involved. That is why marketing is so important—it comes in *twice* in the income equation.

The Scope for Reducing Marketing Costs

For the purpose of this discussion, I want to interpret the term "marketing" rather broadly, to encompass most things that happen to products between farmers and consumers. This includes various stages of transport, storage, processing, buying, and selling—every activity that moves a commodity forward over space and time, changing its nature along the way. Let us look at some evidence to demonstrate the scope for reducing real prices of farm goods and inputs through improvements in marketing and to show how important this might be in helping to alleviate poverty.

In figure 1, we see the classical reduction in real food prices over time, as shown by the price of a representative wheat variety, as quoted f.o.b. ships in Atlantic ports of the United States. From 1960 to 1991, the price of this wheat was roughly halved in real terms.

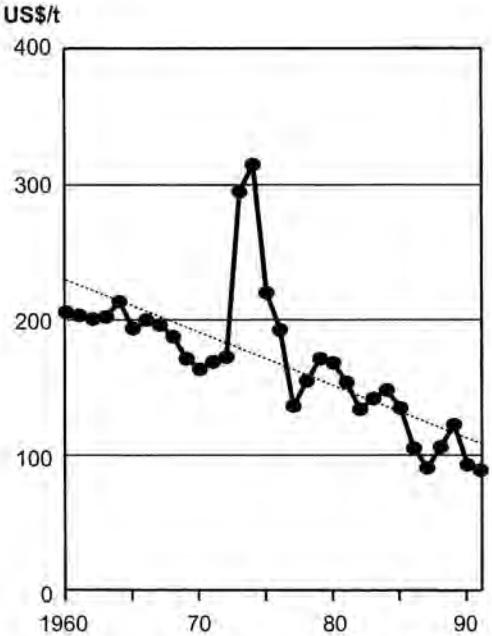

Fig. 1. Prices for soft red winter wheat, f.o.b. U.S. Atlantic Ports (1980 U.S. dollars). Broken line shows trend. Source: World Bank 1993, 57.

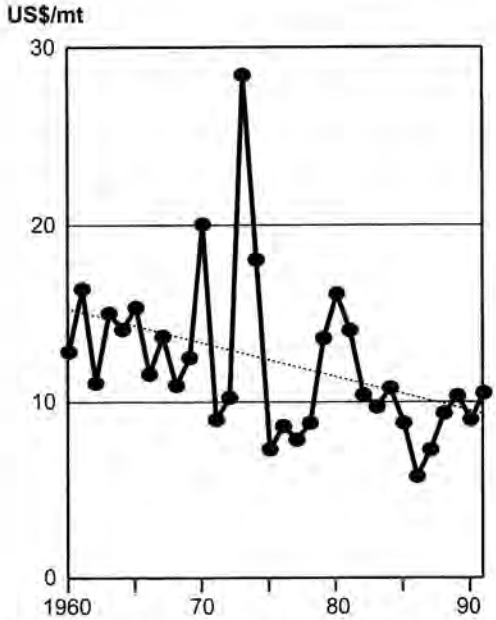

Fig. 2. Cereal freight cost, USA to Europe (1980 U.S. dollars). Broken line shows trend. Source: World Bank 1993, 49.

The main force driving this decline was technological improvement, which allowed farmers to continue making profits from wheat farming, even though real prices fell so markedly.

In figure 2, we see that over the same period, the cost of carrying that wheat to Europe also declined in real terms by about 40 percent. If we broke down the fall in real wheat prices arriving in Europe over this 30-year period, we would find that 95 percent of the decline was due to competitive forces within the USA (among farmers producing the wheat, as well as among merchants marketing it and transporters carrying it), and 5 percent was due to competitive forces in the ocean freight business.

Figure 3 shows a price series for sugar, f.o.b. Caribbean ports, from 1960 to 1991. Although international sugar prices have been more volatile than those of wheat during this period, the trend is nevertheless also downward in real terms, about 35 percent over the period. If we looked at international freight rates for sugar, we would observe a decline in real terms, just as for wheat. And it is important to recall that there have also been real price declines for inputs such as fertilizers. As can be seen from figure 4, in

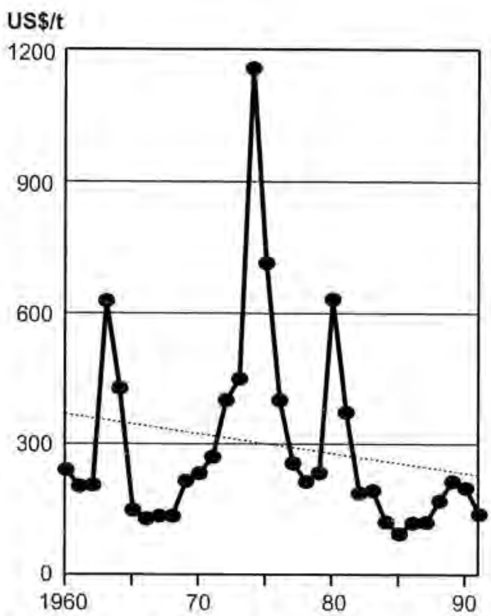

Fig. 3. Prices for sugar, f.o.b. Caribbean ports (1980 U.S. dollars). Broken line shows trend. Source: World Bank 1993, 58.

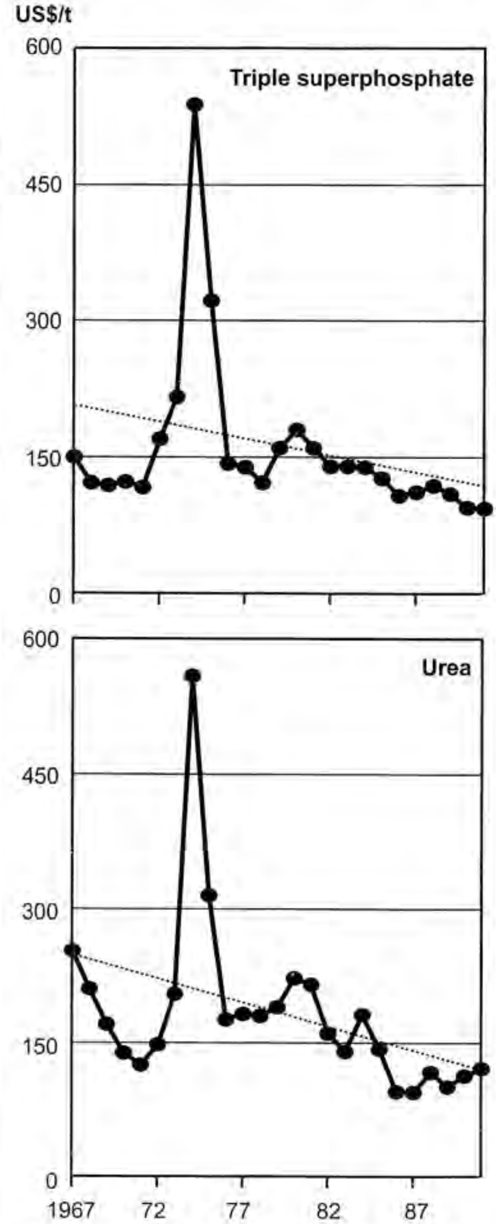

Fig. 4. Prices for triple superphosphate and urea (1980 U.S. dollars). Broken line shows trend. Source: World Bank 1993, 97–98.

the past 25 years the real international price of triple superphosphate has fallen by about 38 percent and that of urea by more than 50 percent.

Sub-Saharan Africa's export commodities have faced similar real price declines in international markets. Table 1 shows how these real prices have fallen between 1970 and 1994. Unfortunately, the technological and marketing changes allowing these price declines to be sustained often happened outside of Africa. As a result, sub-Saharan Africa lost market share in all of its major export commodities during this period, as shown in table 2. Its market shares fell between 1970 and 1990 as follows: cocoa beans from 60 to 41 percent, coffee from 30 to 23 percent, palm oil from 19 to 2 percent, cotton from 16 to 14 percent, and bananas from 6.5 to 2.5 percent. Sub-Saharan Africa lost its market share principally to the Americas for coffee and bananas, to East Asia (especially Malaysia and Indonesia) for cocoa and palm oil, and to Pakistan and the United States for cotton.

In a world of science and competition, then, there is no escape from falling real prices over time. That is why it is imperative for

Table 1. Real world prices of major African export commodities, 1970–94 (1990 US dollars).

	Prices					Change (%)	
Commodity	1970	1980	1985	1991	1994	1980–91	1970–94
Coffee (¢/kg)	457	478	468	183	310	–62	–32
Cocoa (¢/kg)	269	362	329	117	129	–64	–52
Tea (¢/kg)	437	310	289	180	180	–42	–59
Groundnut oil ($/t)	1,510	1,194	1,319	874	939	–27	–38
Palm oil ($/t)	1,037	811	730	332	463	–43	–55
Cotton (¢/kg)	252	284	192	164	161	–42	–36
Tobacco ($/t)	3,938	3,196	2,843	2,182	1,784	–32	–55
Rubber (¢/kg)	185	226	135	99	118	–56	–36
Sugar ($/t)	323	878	130	193	243	–78	–25
For comparison:							
Rice ($/t)	574	603	315	308	335	–49	–42
Wheat ($/t)	250	265	253	140	184	–47	–26
Maize ($/t)	233	174	164	105	102	–40	–56

Source: Delgado 1995.

Table 2. Sub-Saharan Africa: Market share in agricultural exports, 1970–95.

		Exports (000 t)				
Commodity	**Area**	**1969–71**	**1979–81**	**1990**	**1995 (Proj.)**	**Growth 1970-90 (%/yr)**
Cocoa	Sub-Saharan Africa	979	907	1,298	1,386	1.4
	World	1,638	2,052	3,190	3,401	3.4
Coffee	Sub-Saharan Africa	987	900	1,126	1,050	–0.3
	World	3,261	3,649	4,869	4,595	1.6
Palm Oil	Sub-Saharan Africa	186	96	193	190	–2.2
	World	1,002	3,230	7,884	11,417	10.4
Cotton	Sub-Saharan Africa	627	372	699	815	1.3
	World	3,929	4,558	5,035	6,820	1.5
Bananas	Sub-Saharan Africa	389	246	234	236	–4.5
	World	5,929	6,900	9,330	10,068	1.3

Source: World Bank 1992.

sub-Saharan Africa to lower its real costs of production and marketing, not only to be able to compete in international markets, but to bring down the levels of domestic poverty as well. Let us look at how much improvements in marketing efficiency might contribute to the latter goal.

I would like to make some comparisons of marketing costs, including transportation, between the United States and Kenya. Tables 3 and 4 show, for a few years, the differences between the average prices American farmers receive and the average export prices of wheat and maize. The differences are typically US$20/t to US$30/t, or 20 to 25 percent. The simple average for maize, over the decade from 1984 to 1993, is a price increase of about 20 percent. The maize in these cases is possibly coming to the U.S. ports from 1,000 to 1,700 kilometers away. Now let us take one year, 1992, and move this maize from the United States to Mombasa, Kenya, and on to Western Kenya. The costs are shown in table 5. We see that in that year, taking the maize from U.S. farms to Gulf ports added about US$23/t to the cost, shipping it to Mombasa added US$43/t, and taking it from Mombasa to Western Kenya would have added about US$82/t, that is, more than the total cost of bringing it all the way from a U.S. farm to the port of Mombasa. The distance from Mombasa to Western Kenya is about 880 kilometers. If we assume the average distance the maize came from farms to U.S. Gulf ports was 1,200 kilometers, the marketing costs were almost five times as great per tonne-kilometer in Kenya as they were in the United States. The breakdown of these costs in Kenya is outlined in table 6.

What if the costs from Mombasa to Western Kenya had been only three times as great per tonne-kilometer as the costs in the United States, instead of five times? The price of the maize in Kenya would have then been 13 to 14 percent lower than the level shown in table 5. How might that affect the poor?

Table 3. US soft red winter wheat: Farmer and export prices.

	Prices (US$/t)			
Year	Farmer	f.o.b. Gulf ports	Difference	Difference (%)
1990	102.2	129.1	26.9	26
1991	96.6	126.1	29.5	31
1992	117.2	145.1	27.9	24
1993	103.6	134.8	31.2	22
Avg	104.9	133.8	28.9	28

Sources: USDA 1994, A-69, and World Bank commodity price data.

Table 4. U.S. maize: Farmer and export prices.

	Prices (US$/t)			
Year	Farmer	f.o.b. Gulf ports	Difference	Difference (%)
1984	103.5	135.9	32.4	31.3
1985	87.8	112.2	24.4	27.8
1986	59.1	87.6	28.5	48.2
1987	76.4	75.7	na	na
1988	100.0	106.9	6.9	6.9
1989	92.9	115.5	22.6	24.3
1990	89.8	109.3	19.5	21.7
1991	93.3	107.4	14.1	15.1
1992	81.5	104.2	22.7	27.9
1993	100.4	102.1	1.7	1.7
Avg	88.4	105.7	17.3	19.6

Sources: USDA 1994, A-63, and World Bank commodity price data.

Table 5. Maize: Cost of transport from USA to Kenya.

Item	Price or cost (US$/t)	Addition to cost (US$/t)	Addition to cost (%)
U.S. farmer price	81.5		
f.o.b. Gulf ports	104.2	22.7	27.9
c.i.f. Mombasa	147.5	43.3	41.6
c.i.f. Western Kenya	229.2	81.7[a]	55.4

Sources: USDA 1994; World Bank, commodity price data; Nyoro 1992, 37.

a\ Estimated to be US$104 in February 1995.

Table 7 shows how important food expenditures are to the lower income groups in Kenya. Using rather old data, which are not markedly different today, we see that for the lowest income households more than half of their expenditures were on food and more than 10 percent on maize alone. If more competitive, efficient marketing had reduced the price of food by 15 percent, the real incomes of the lowest two income groups would have increased by around 8 percent. This alone would have been enough to raise perhaps 5 percent of the population above the absolute poverty line. It is a tragedy that ill-advised policies often prevent the emergence of competitive, efficient marketing and thus prevent the poor from realizing the benefits that might come from such reduced marketing costs.

An important element of the maize policy regime in Kenya before the recent reforms was a set of severe controls on maize movement, which introduced a number of distortions into the market. A study (Argwings-Kodhek 1992) carried out while those movement controls were in place estimated the potential cost reductions and sources of efficiency in Kenya's maize trade. Among other things, the study found that:

- Price differentials between different locations varied markedly from place to place and from time to time and were often substantially greater than the costs of transportation or storage would suggest, or what traders regarded as a

Table 6. Kenya: Maize import parity price.

Cost	Kwale (30 km)	Nairobi (487 km)	Nakuru (644 km)	Siaya (882 km)
c.i.f. Mombasa (US$/t)	148	148	148	148
Exchange rate (K Sh/US$)	31	31	31	31
c.i.f. (K Sh/t)	4,588	4,588	4,588	4,588
Handling (K Sh/t)[a]	1,047	1,047	1,047	1,047
Rail to Nairobi (K Sh/t)	0	558	558	558
Rail to station (K Sh/t)	0	0	192	492
Road to station (K Sh/t)	93	0	0	420
c.i.f. Yellow maize (K Sh/t)	5,728	6,193	6,385	7,105
White maize premium	1.1	1.1	1.1	1.1
c.i.f. White maize (K Sh/t)	6,300	6,812	7,024	7,815

Source: Nyoro 1992, 37

a\ Comprising insurance, K Sh 46; stevedoring, K Sh 252; inspection, K Sh 19; port handling, K Sh 55; port charges, K Sh 4; wharfage, K Sh 68; bagging K Sh 121; bags, K Sh 244; port to warehouse, K Sh 93; offloading, K Sh 27; storage, K Sh 36; loading to rail, K Sh 27; miscellaneous, K Sh 34.

Table 7. Kenya: How reducing marketing and transport costs might affect income.

Total household expenditure (K Sh/month)	Expenditure (%)		Assumed price reduction from marketing (%)	Income increase (%)	
	On food	On maize		Food	Maize
<300	56	11	15	8.4	1.7
300–599	52	11	15	7.8	1.7
600–899	45	9	15	6.8	1.4
900–1,499	36	6	15	5.4	0.9
>1,499	20	3	15	3.0	0.5

Source: Expenditure data from the 1981/82 Rural Household Survey cited in Ephanto 1992.

Note: The average poor person was 30% below the absolute poverty line (K Sh 106 per month per adult equivalent) in 1981/82 and 40% below the absolute poverty line (K Sh 485 per month per adult equivalent) in 1992. An estimated 48% of the population was below the absolute poverty line in 1981/82 and 46% in 1992.

minimum margin for moving the grain. In economic terms, the markets were not well *integrated*, either over space or time.

- The per-tonne costs of maize transport were continuously reduced as the scale of the transportation increased: By bicycle or donkey, the cost was K Sh 11/km; by small van, K Sh 6.6/km; by 4-tonne truck, K Sh 3.3/km; by medium-sized truck, K Sh 2.4/km; by large lorry (12 to 15 tonnes), K Sh 0.6/km; and by rail over 1,000 kilometers, K Sh 0.7/km.
- For moving maize in a 15-tonne lorry from Kitale, one of Kenya's main growing areas, to Machakos, one of the deficit districts (a round trip of about 1,000 kilometers), the single largest cost was the permit to carry the maize, which represented 28 percent of the total cost. Although fuel made up 32 percent of total cost, it was spread over the whole round trip, while the permit for maize was useful only in one direction. As Argwings-Kodhek (1992) pointed out, this was not a loss to society, but it did represent a transfer of income from farmers, traders, and consumers to those who had permits to sell.
- If the maize movement controls then in force (44 bags, or 4 tonnes in a single load) had been relaxed, it was estimated that transport costs could have been decreased by 38 percent over a typical shorter route. This alone would have reduced the market price of maize by at least 6 percent.

Before we leave maize, let us look for a moment at the next step in the chain, milling. Prior to the latest round of reforms in the maize sector in Kenya, the National Cereals and Produce Marketing Board had a monopoly in maize marketing. It controlled the number and location of maize mills because they had to register with it before they could purchase maize from it. Furthermore, official pan-territorial and pan-seasonal pricing set limits on both spatial and seasonal trade by providing no incentives for either. In fact, the bulk of the milling capacity was in consuming (maize-deficit) areas because the maize itself was the millers' largest cost, and NCPB provided it at the same price all over the country. There was also tremendous over-investment in sifted maize milling capacity because it didn't pay, at official prices, to serve anything but the most immediate local market. With the liberalization of maize marketing, which eliminated official pricing, some believe there will be a big shakeout of the milling industry (Mukumbu 1992). Some of the elements of this are likely to be as follows:

- A substantial decline in the number of sifted maize mills, perhaps from the 30 present under the old policies to as few as three large-scale mills
- A shift of large-scale sifted maize mills to the surplus (producing) regions, since flour is cheaper to transport than maize grain
- Better use of capacity in the remaining large-scale sifted maize mills, with these pushing the less efficient medium-scale ones out of business
- A shift in consumer demand toward unsifted maize flour, produced in very small, *posho* mills, whose costs of processing are lower still (table 8 compares costs of maize milling in three types of mills in Kenya)

To demonstrate that these comments do not apply only to food, we need to note that liberalization of the coffee industry in Kenya is also taking place. "Since December 1994, two commercial private millers . . . have been licensed to process coffee. Coffee milling had previously been monopolized by Kenya

Planters Cooperative Union (KPCU) . . . . In a bid to compete with the new firms, KPCU lowered its milling charges from US$65/t to US$60/t during the second quarter of 1995. It also plans to upgrade and decentralize its milling operations in the near future" (World Bank, internal memo, August 1994).

And to demonstrate that the high costs of marketing do not apply only to Kenya, let me cite some data from Ethiopia from a few years ago (World Bank 1987). At that time, the costs of transportation between the port of Assab and Addis Ababa were about EB 153/t, or almost US$75/t at the going exchange rate. The distance, just over 880 kilometers, was almost exactly the same as from Mombasa to Western Kenya. Within Ethiopia, transportation costs were equally steep. Depending on the region, costs from the farm to the principal town ranged from US$20/t to US$63/t, averaging US$41/t for a trip of about 325 kilometers. From the principal town to Addis Ababa, comparable costs were US$15/t to US$67/t, averaging US$35/t for a trip of just over 400 kilometers. These costs were typically up to seven times as large per tonne-kilometer as comparable costs in the United States.

Table 8. Kenya: Maize milling comparative costs, 1991 (K Sh/t of maizemeal).

Cost item	Large mills	Small mills	Posho mills
Fixed inputs	396	146	97
Labor inputs	231	214	84
Intermediate inputs	165	276	160
Total	792	636	341
Capacity utilization (%)	23	41	54

Source: Mukumbu 1992.

Finally, as an example of the problems facing fertilizer within sub-Saharan Africa, I present some data about fertilizer costs in Malawi (table 9 and fig. 5). The most important thing to note is the extremely wide wedge between the international price for urea and the costs of getting it to the farmer in Malawi. This difference is made up largely of transport costs from the coast to Malawi and within the country. In most of the years shown in table 9, these transport costs more than doubled the international price by the time it reached the farmer. Furthermore, while the international price was trending downward over the period, even in nominal terms, the cost of landing the fertilizer in Malawi was rising steadily (fig. 5). The challenge this poses for inducing farmers to adopt fertilizer on their small farms is obvious, even if the

Table 9. Malawi: Exchange rates, transportation costs, and fertilizer prices, 1984–90.

Year	Exchange rate (K/US$)	Urea price (US$/t)	Urea price (K/t)	Transport cost to import railhead (US$/t)	Transport cost to import railhead (K/t)	Transport cost to railhead to Malawi (K/t)	Total cost including transport (K/t)	Smallholder price (K/t)	Market price (K/t)	Total cost including transport (US$/t)
1984	1.4134	171	242	38	47	167	456			323
1985	1.7191	136	234	38	65	178	477			277
1986	1.8611	107	199	38	71	179	449	520		241
1987	2.2087	117	258	35	77	245	580	540	604	263
1988	2.5613	155	397	35	90	296	783	600	851	306
1989	2.7595	132	364	55	152	340	856	740	1,020	310
1990	2.7289	157	428	50	136	365	929	814	1,039	340

Source: Donovan 1994, 39–40.

fertilizer were available and even if the farmers had the credit they needed to purchase it. Faced with a situation like this, governments typically reach for the subsidy tool. But it is a rather futile substitute for reducing transport and marketing costs.

These examples give some idea of the scope for reducing transport and marketing costs and of the magnitude of the problems facing policy makers if they are to realize the gains from increasing efficiency in these areas, as well as ensuring that the new technologies generated by research are taken up by farmers. The rewards for making the needed reforms, however, include lower real costs of inputs to farmers, lower food prices for consumers, lower costs of raw materials for agro-industries, greater price stability from season to season, a more rapid uptake of new technologies, and higher returns to investments in research and extension.

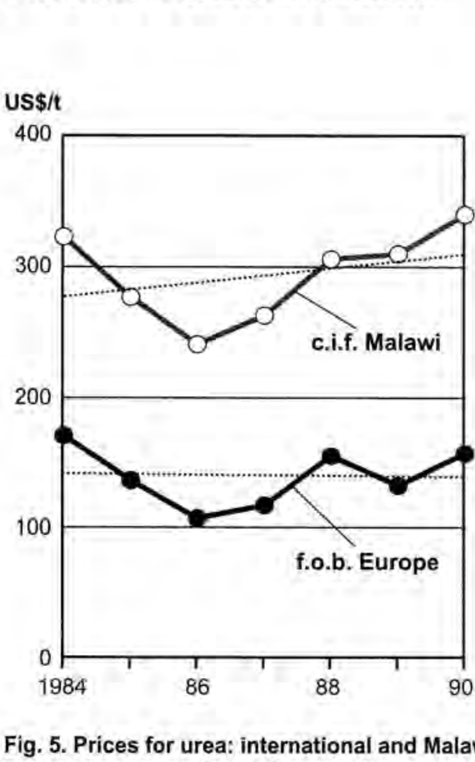

Fig. 5. Prices for urea: international and Malawi. Broken line shows trend. Source: Donovan 1994, 39–40.

Restating the Argument

At this point I would like to repeat in a different way the argument with which I began this paper. The argument has three parts:

1. Agricultural growth has a substantial impact on economic growth, probably greater that the impact of any other single sector, in most sub-Saharan African countries.
2. There are sizable opportunities for reducing the real prices of agricultural products and inputs, through more efficient, competitive marketing as well as through investments in technology improvement.
3. The way to realize these opportunities, as far as marketing is concerned, lies through fostering a competitive private sector, but this is not likely to happen just by withdrawal of the public sector from the arena—there are lots of things for the public sector to do.

Agriculture's Growth Linkages

Studies in sub-Saharan Africa initially estimated agricultural growth multipliers at about 60 percent of those found in Asia, around 1.5 compared with 1.83. That is, a \$1.00 increase in value-added from agricultural tradables induced an additional \$0.50 of rural income in sub-Saharan Africa, compared with an additional \$0.83 in those Asian countries that had been studied (Haggblade, Hazell, and Brown 1989). The authors cautioned, however, that the large share of nonmarketed goods and services in consumption in Africa may have given the estimates of growth multipliers there a downward bias.

Using a model of the Kenyan economy and validating it with disaggregated data from 1977 to 1991, Block and Timmer (1994) demonstrated that the long-run agricultural growth multiplier was about 1.64, while the long-run growth multiplier for non-agriculture was 1.23; in other words, net of direct growth effects, the multiplier from agriculture was almost three times the multiplier from non-agriculture. If agriculture were to grow 1 percent faster, total GDP would grow 0.43 percent faster and non-agriculture 0.2 percent faster. The indirect contribution of non-agriculture to more rapid growth was only 20 percent of its total contribution, while the indirect contribution of agriculture to more rapid growth was 33 percent of its total contribution.

A comprehensive study (Delgado, Hopkins, and Kelly 1994) completed more recently concluded that agriculture's growth linkages in sub-Saharan Africa were much higher than previously thought, with additional income arising from the initial (exogenous) stimulus at least as great as the initial stimulus (i.e., multipliers typically greater than 2.0 and, in a case study in Burkina Faso, as high as 2.88). The study noted that it was very important that the initial stimulus come from outside the *region* with whose growth multipliers policy makers are concerned and that the stimulus be targeted at *tradable* items of agricultural production. Stimulating the non-tradable sector alone (through technological change, lending, etc.) was likely to be a one-shot thing and would result only in "mountains of unsold produce by the roadside" (Delgado, Hopkins, and Kelly 1994, xxii).

While *tradable* agriculture (producing goods exported from the *region* under consideration) was the basic growth engine, alone capable of providing the widespread and recurring income source needed for an economically sustained rural growth process, growth multipliers arose when people spent increments to income on *non-tradables* (with respect to the region of interest), i.e., those things that by definition could not be imported (or exported). The growth impact came from drawing under-employed resources into production to meet new local demand. The multiplier effects of consumption linkages might be equal to, or greater than, those of production linkages (e.g., for intermediate goods used in agricultural production such as tools). Consumption growth multipliers worked through consumer spending on services (which by definition were non-tradable), non-tradable farm goods, and local nonfarm goods (including food processed by farm households).

Reducing the Costs of Marketing Agricultural Outputs and Inputs

The study concluded that to get the best out of the growth linkages offered by non-tradable rural consumption items, it helped if those items had a price-elastic supply, i.e., that their production response to increases in their price was high. Efforts to increase the price elasticity of supply of the non-tradables in demand could be beneficial. This increase in price elasticity was typically achieved (on the production side) through research, ready supplies of inputs, and good support services and (on the trade side) through investments in infrastructure, friendly institutions, and making it easier to obtain imports. The role of public goods, such as research, was a key part of this process and was very important for getting the most out of growth linkages.

The technology part of this is the focus of *agricultural research*. The marketing part is the focus of *policy* and investments in *human capital, services,* and *infrastructure*. Removing price controls may be an essential first step in encouraging competitive private marketing of agricultural products and inputs, but the response has sometimes been disappointing because of a complex of other inhibiting factors that need to be addressed. The most important among these is poor roads and transport services. But there usually remain, from the period of restricted trading, a web of controls embodied in regulations relating to licensing, trading hours and locations, weights and measures, transportation services, movements of goods, and so on. A comprehensive review of these regulations is needed to realize the gains in efficiency that can come from more competition. In addition, new regulations may be needed, especially relating to enforcement of contracts and the orderly formation and dissolution of businesses. Private traders often have problems gaining access to credit and after long years of proscribed activity may lack the necessary management skills. There is, in most countries of sub-Saharan Africa, a tremendous information gap in the availability of market intelligence. Public policy in all these areas has a long way to go in most countries. And many countries are even further away from having a viable, dynamic, competitive private sector that will be able to realize the gains to be had from more efficient marketing.

Let us take Ethiopia as an example. In 1991/92, the public-sector Agricultural Marketing Corporation (now the Ethiopian Grain Trading Enterprise) had an estimated storage capacity greater than 1 million tonnes, compared with only 9,530 tonnes shared among 4,424 licensed grain traders, an average of 2.15 tonnes per trader. The private sector thus had 0.9 percent of the storage capacity of the large, public-sector enterprise (unpublished draft study of grain market reform and food security in Ethiopia, June 15, 1995). A 1994 survey showed that the average grain trader at Arba Minch market had working capital of EB 15,000 (US$2,500 equivalent), enough to buy only 13 tonnes of maize at the prevailing wholesale price of EB 115/100 kg. Traders possibly had as few as 153 trucks among all of them. Traders needed training in bookkeeping, stock management, and quality control, as well as access to market intelligence and credit.

Comparing the pre-reform (1986/87–1989/90) and post-reform (1991/92–1994/95) periods in Ethiopia, grain output increased only by 13 percent, while average producer prices for grains increased by 320 percent in nominal terms (from EB 29.33/100 kg to EB 123.25/100 kg) and 290 percent in real terms (from EB 28.47/100 kg to EB 111.03/100 kg). More interestingly, the average share of producers in the final consumer price was estimated to have increased from 23 percent to 78 percent and their average share in the import parity price from 44 percent to 57 percent. These data imply that average consumer price, in real terms, had increased by 14.9 percent (from EB 123.78/100 kg to EB 142.23/100 kg). This shows that already some efficiency gains have been realized in marketing, in spite of the private sector being still in a very early stage of development.

Fertilizer as a Key Input

Let us return to fertilizer, a key input that mediates between agricultural research and getting results from new technologies in farmers' fields. Fertilizer is also an input about which there has been much discussion of policy and for which substantial efforts have been made in many countries to reduce its costs and influence its uptake by farmers.

Fertilizer use is extremely low in sub-Saharan Africa. Average application of plant nutrients per unit area of arable land (15 kg/ha in 1992/93) is substantially below that in South Asia (74 kg/ha) and far below that in China (301 kg/ha). Some have maintained that this low fertilizer consumption is itself a sufficient indicator that an agricultural transformation has yet to take place in sub-Saharan Africa. Although one of the reasons for the differences in consumption is irrigation, which is much more widespread in Asia, rainfed areas of India receive at least three times as much fertilizer per hectare as those in sub-Saharan Africa, and serious fertilizer supply constraints still exist in many countries of sub-Saharan Africa.

Fertilizers are generally expensive in African countries as a result of small procurement lots; weak bargaining positions; high shipping, handling, and domestic transport costs; and inefficient marketing by public agencies. Governments have been slow to relinquish their typically close involvement in fertilizer importing and marketing at least in part because of continuing in-kind aid by bilateral donors. As a result private marketing of fertilizers is not well developed in many countries. Sub-Saharan Africa accounted for only about 0.8 percent of total world consumption in 1986 and about 1 percent in 1991. It thus remains a very insubstantial player in the fertilizer market, which in part accounts for the high costs of fertilizer procurement in many countries. Leaving aside South Africa, sub-Saharan Africa is also a negligible *producer* of fertilizer, accounting for less than 0.4 percent of world output. Nigeria and Zimbabwe between them accounted for more than 80 percent of that production in 1991.

One of the clear messages of recent experience in sub-Saharan Africa is that liberalization of fertilizer marketing by itself is not enough if the goal is to accelerate fertilizer use quickly. In fact, the desperate need to get more fertilizer on to the land in Africa (for both agricultural growth and environmental reasons), coupled with the slow pace of private-sector development, is what lies behind the well-intentioned advocacy of fertilizer subsidies and behind proposals for parastatal agencies that would perform all functions in fertilizer supply—forecasting needs, importing, distributing, marketing, providing advice, and providing credit. If a private-sector model is to be followed in the interests of long-term efficiency and sustainability, or only because public-sector budgets can no longer bear the burden of public-sector fertilizer supply, something more is needed than merely freeing up markets and waiting for the private sector to seize the opportunities.

What should that something be? Preparations made recently for a fertilizer project in Ethiopia suggests the kinds of steps that may be necessary to increase fertilizer consumption and develop private marketing and distribution at regional and national levels.

First, it is important to remind ourselves of the main reasons why farmers don't use enough fertilizer:

- Lack of knowledge about fertilizer, or about what kinds and amounts of fertilizer to use, and how and when to apply it

- Fertilizer use not financially viable because of high costs of getting it to fields (including unavailability in small enough packages), inadequate response from lower grade crop varieties or poor seeds, inadequate prices or late payments for crops, risk of crop loss from adverse weather, and inability to put together other elements of the package of inputs that would make the crop profitable (especially constraints on labor or unavailability of other purchased inputs)
- Unavailability of fertilizer within any reasonable radius (equivalent to a price that is infinitely high) or unavailability of the correct formulation of fertilizer
- Inability to raise sufficient funds to purchase fertilizer, either because of lack of access to credit or lack of cash arising from late payments for crops

Estimating the relative importance of the various constraints outlined for different kinds of small farmers in different areas is a major research task.

Second, and derived from these problems faced by farmers, some of the most important things for policy makers to focus on are:

- Thorough soil testing to recommend the right formulation for each major locality and crop, taking into account trends in soil acidification and environmental effects
- Up-to-date research on fertilizer response functions, which, in combination with soil testing and input-output prices, results in correct (optimal) application recommendations for all main situations
- Extension of appropriate fertilizer recommendations to farmers and promotion of fertilizer use
- Careful planning to make the most of donor aid including discouraging aid-in-kind (because it can force the wrong formulations), encouraging untied monetary aid where possible, and distributing any remaining aid-in-kind through the free market
- Adequate, freely available foreign exchange for private fertilizer importers, with minimum government interference, in any case excluding physical quotas in licensing
- Exploration of the economies to be gained from bulk procurement of fertilizers for import
- A government role confined to monitoring, planning, providing guidelines to donors, creation of the right incentive framework, research, providing market outlook and fertilizer information through agricultural extension, and regulating quality standards
- Adequate access to credit for private importers, domestic distributors, and farmers
- Attention to factors constraining fertilizer use by farmers (see above), especially incentives for crop and livestock production on the demand side and transport and packaging bottlenecks on the supply side
- Promoting, in some countries, the application of locally available products, such as rock phosphate, or their use in domestic manufacture of fertilizer (but this needs to be carefully examined case-by-case)

The Ethiopia National Fertilizer Sector Project

A World Bank project that has just started in Ethiopia (World Bank 1995) seeks to address many of the same problems as those experienced throughout sub-Saharan Africa. In 1992 fertilizer consumption in Ethiopia had increased to 156,000 tonnes (114,000 tonnes of nutrients) from just over 40,000 tonnes in 1980, but consumption per hectare of arable land (8 kg nutrients/ha) was below the average for sub-Saharan Africa and among the lowest in the world. An estimated 20 percent of the country's 6 million farm families used fertilizer, 95 percent of which was applied to foodgrains. Since diammonium phosphate constituted 80 percent of fertilizer sales and urea 19 percent, there was a serious shortfall in nitrogen—the ratio of nitrogen to phosphorus being about 1:1.8 compared with an extension recommendation of 1:1.1.

Imports and marketing were controlled totally by the state, through collaboration between the Ministry of Agriculture and the monopoly parastatal Agricultural Inputs Supply Corporation (AISCO), until mid-1993, when the Transitional Government of Ethiopia announced a new National Fertilizer Policy. Prices were administered and set on a pan-territorial basis, and a 15 percent fertilizer subsidy was introduced to soften the impact of a more than 100 percent devaluation of the domestic currency. The new policy of 1993 calls for involvement of the private sector throughout the entire fertilizer trade, but only a small, inexperienced private sector exists to call on, so the central goal of the project is to increase fertilizer supplies by ensuring that a viable private sector comes into being, is built up, and becomes sustainable.

The main proposals of the project are as follows:

- The fertilizer price subsidy, which the government regarded as temporary from its initiation, would be phased out over a 2-year period and capped as to absolute amount in the meantime.
- Pan-territorial prices would be phased out gradually, beginning at the retail level, progressing to wholesale, with total decontrol after 3 years.
- The monopoly of the Agricultural and Industrial Development Bank in providing credit for agricultural inputs would be abolished and the Commercial Bank of Ethiopia, with many more rural branches, would be expected to provide trade and working capital finance for the fertilizer sector.
- The private sector, which already has been given the green light to import and market fertilizers without any restrictions, would be assured equal access to foreign exchange from all available sources, including the IDA import credit that would be forthcoming under the project. The government would also promote fertilizer use in the more remote areas by selecting, on a competitive basis, traders to operate in these areas and compensating them for their additional costs of doing so (especially transportation).
- AISCO would be expected to play an active role in building up the private retail network. It would do this by selling the bulk of the fertilizer it handles through private agents (including cooperatives) and by preparing a plan for phasing out operations of all of its marketing centers within 3 years.
- The government would discuss with donors the possibility of their harmonizing procurement procedures so that fertilizers could be imported at the most competitive prices.
- The government would also develop and enforce fertilizer specifications, quality standards, and packaging regulations, while providing specific education to fertilizer dealers and farmers relating to

the standards and safe handling and storage of fertilizers.

- The project would finance technical assistance and training for all participants in the private-sector marketing system, at all distribution stages, including cooperatives, which are expected to play a much larger role in the future.
- The project would also finance investments in a dockside bagging facility in the main port, laboratories for soil testing and for producing rhizobial cultures (to boost nitrogen-fixing crops), a laboratory to develop and enforce fertilizer quality standards, equipment for biogas development (from animal manure), equipment for the agricultural extension services, equipment for the Ministry of Agriculture to lay down fertilizer trials and demonstrations in farmers' fields, and requisites of a new National Fertilizer Industry Agency. The latter agency would implement the project, coordinate and monitor all project activities, and be the spearhead of the national fertilizer-promotion effort.
- Training would be offered within Ethiopia on international fertilizer marketing, port handling, integrated plant nutrient supply systems, fertilizer quality control, soil testing, fertilizer wholesaling and retailing, inventory control and warehouse management, biofertilizer production (rhizobia cultures), storage and transportation, biogas technology, and cooperative management. There would also be support for some training programs outside the country, and a twinning arrangement would be explored with one or more reputable institutions specialized in related fields of expertise.
- The project would include measures to promote fertilizer use and stimulate demand, with the aim of more than doubling fertilizer consumption over 5 years. These measures would include an annual fertilizer workshop bringing together all interested parties to estimate needs, plan, and prepare year-to-year strategies for promoting fertilizer; agricultural research and extension programs focusing on working out and spreading better fertilizer recommendations for farmers (including balanced nutrient use for care for the environment); preparing explicit plans for expanding fertilizer use; implementing a minikit program to introduce a targeted number of new farmers each year to fertilizer use, and close collaboration with other activities of the project such as biofertilizer and biogas development, waste recycling, and soil testing; a program by AISCO to introduce smaller fertilizer packages for small-scale farmers; using all available media to promote fertilizer; and collaborating with Sasakawa-Global 2000 in laying out a large number of demonstrations each year for 5 years.
- The National Fertilizer Industry Agency would be charged with putting considerable effort into facilitating, accelerating, and solving problems in the supply chain from imports through the port and the transportation network into the hands of the domestic fertilizer trade. This would include a special focus on foreign exchange availability and identifying and dealing with any gaps or shortfalls that may develop in the supply chain.
- The project would finance more than half of incremental fertilizer imports during the project's life.

The approach proposed in this large, important national fertilizer project (World

Bank 1995) is an "administered" solution to the many problems facing the fertilizer sector. It is based on the principles of using the available strengths of the public and cooperative sectors and mixing these with the growing strength of the private sector, which would be actively promoted. The project claims as advantages of this mixed approach, "avoiding a vacuum and sustaining fertilizer consumption levels during the transition period, and giving time to the private sector to assimilate change, build confidence as well as experience, and achieve sound growth."

There are significant risks in this approach. Among them are possible conflicts between emerging private-sector interests and remaining public agencies over estimates of fertilizer needs and gaps; the possibility that the parastatal AISCO, having control over selecting its own marketing agents and planning its own withdrawal from the marketing system, may find itself unable (or unwilling) to implement its own demise as smoothly as the project envisages; the possibilities that continued public-sector control over promoting fertilizer in remote areas and that arranging for AISCO to fill any gaps it sees developing in the supply chain may interfere with private-sector development by maintaining a substantial element of uncertainty; and the possibilities for overlapping responsibilities and inefficiency in the operation and coordination of such a substantial number of public agencies.

Nevertheless, in Ethiopia, as in many other countries of sub-Saharan Africa, it seems unlikely that an efficient private fertilizer marketing and distribution system would develop quickly enough of its own accord, merely given the go-ahead to do so. Especially critical are the port facilities, the roads, and the financing needs of the system, in all of which it appears necessary for explicit public-sector involvement in attempts to overcome the legacy of decades of neglect. The experiment in Ethiopia is a serious effort to seek better ways to allocate scarce resources than to subsidies and to take as exhaustive a series of actions as possible to promote fertilizer use and establish fertilizer markets on a sound and sustainable basis. The experiment should be watched closely to learn lessons of experience as it proceeds and to make the necessary adjustments to ensure its success.

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No-till and Reduced Tillage for Improved Crop Production in sub-Saharan Africa.

J. Hebblethwaite, R. Soza,
A. Faye, N. Hutchinson

The annual rate of population growth in Africa has increased from about 2.7 percent from 1965 to 1980 to about 3.1 percent since 1980. However, agricultural growth has held at about 1.7 to 1.9 percent per annum since 1965. Most of this growth has been from the expansion of cultivated area rather than from increases in yield. With population growing faster than food output, per capita food production has fallen. This decline has resulted in a rapid increase of food imports and food aid (4% and 7% per year, respectively, since 1974). Despite the increases in food imports, food intake per person in Africa has been estimated at 87 percent of requirements in the 1980s (Cleaver 1993).

Expansion of cropped area in Africa has resulted in rapid deforestation (3.7 million hectares per year) as existing cropland is abandoned due to loss of fertility, soil degradation, and severe erosion (Cleaver 1993). The problem is compounded in many countries by massive migration of rural populations to urban centers, resulting in serious shortages of agricultural labor in the countryside. In many rural areas, much of the crop production is done by the women and children who remain behind. To reverse the deterioration in per capita food production in Africa, it is essential that agricultural growth be increased to 4 percent per annum. This can be best accomplished through the use of improved crop varieties and the adoption of practices that restore soil fertility, protect the soil from erosion and degradation, and make labor use more efficient. This paper concentrates on no-till and reduced-tillage crop production as a means to achieve these goals.

No-till is any practice that leaves the soil undisturbed from harvesting to planting except for the insertion of holes or slots in the soil with manual equipment or specially adapted planters to introduce seed and fertilizer. Reduced tillage (or conservation tillage) is any practice that reduces or changes tillage to maintain enough surface residue to protect the soil from erosion throughout the year.

Both require that a herbicide be applied to kill existing vegetation prior to planting. This is accomplished by foliar-acting herbicides such as Roundup, a glyphosate-based product from Monsanto, which has attractive environmental properties and very low mammalian toxicity. Roundup Dry, which is packaged in sachets of 130 g, is more suited to the small-scale farmer than a flowable formulation because it eliminates the need

J. Hebblethwaite is Executive Director, Conservation Technology Information Center, West Lafayette, Indiana, USA, **Roberto Soza** is Agronomist, CIMMYT, Accra, Ghana, **A. Faye** is Coordinator, On-farm Productivity Enhancement Project, Winrock International, Dakar, Senegal, and **N. Hutchinson** is with Monsanto Company, Brussels, Belgium.

for measuring and thereby diminish applicator exposure, it avoids product adulteration, and it significantly reduces container disposal concerns.

The Benefits of No-till

In trials and demonstrations in Ghana, the Crops Research Institute (CRI), the Department of Agricultural Extension, and SG 2000 have shown that the costs of producing annual crops under no-till are similar to those of crops produced with conventional tillage. However, labor saving and other benefits of no-till are substantial (table 1).

Table 1. Comparative costs of maize production under conventional and no-till systems in Ghana, 1995.

Practice	Cost (¢ 000/ha) Conventional	No-till
Slashing	–	25.0
Pre-plant vegetation control		
Spraying	–	10.0
Roundup Dry[a] (20 sachets/ha)	–	50.0
Plowing	37.0	–
Harrowing	25.0	–
Planting		
Labor	12.5	15.0
Seed	13.5	13.5
First weeding	30.0	–
Fertilizer		
Application	15.0	15.0
NPK fertilizer (125 kg/ha)	56.2	56.2
Second weeding	25.0	25.0
Nitrogen		
Application	15.0	15.0
Urea (125 kg/ha	46.2	46.2
625 ml actellic	13.8	13.8
Harvesting	15.0	15.0
Cost of delivery	5.0	5.0
Total cost	309.2	304.8

Source: Sasakawa Global 2000 and Crops Research Institute, Ghana.

a\ 42% active ingredient glyphosate granular formulation in 130 g sachets.

In conventional tillage systems, 55 percent of the costs are for land preparation and labor; these activities represent only 35 percent of the costs in no-till production. With conventional tillage it can take 25 to 35 person-days/ha to prepare a seedbed, plant, and keep the crop weed-free, while in no-till this can be done with 12 to 17 person-days. Families using no-till will be able to handle spraying, planting, and weed control without having to rely on contracted labor and equipment to do the plowing, harrowing, and extensive weeding needed for conventional tillage. This will permit them to plant at the optimal time for high yields. Families will also be able to handle a larger area of land, resulting in increased food production. This is especially advantageous for women whose husbands are away, working in the cities.

Yield benefits under no-till can be significant. In on-farm trials conducted in Ghana, maize yields consistently exceeded yield from conventional practice in three agroecological zones (table 2). Higher yields result from reduced weed competition and the presence of mulch, which has moisture-saving benefits.

Table 2. Maize yield in on-farm trials under no-till and conventional systems in three agroecological zones, Ghana, 1994.

Tillage treatment	Herbicide applied[a] (sachets/ha)	Yield (kg/ha) Forest	Transition	Guinea savannah
No-till	13	2,916	1,479	4,292
No-till	20	2,454	1,706	4,532
Conventional	–	1,867	947	3,154
LSD 0.05		528	382	1,011
CV (%)		16	16	18

Source: Sasakawa Global 2000 and Crops Research Institute, Ghana.

a\ Roundup Dry.

Mulch, formed from the crop residue and weeds sprayed prior to planting, breaks compacting water droplets, increases moisture penetration, and reduces erosive run-off. Work by Baker and Johnson (1979) in the USA in the 1970s dramatically demonstrated the reduction in water run-off and erosion from no-till (table 3).

The benefits of reduced erosion, improvement in soil quality, and better water retention plus the reduction in input cost from no-till has resulted in rapid adoption in the USA, which has 16 million hectares under no-till crop production. No-till is growing even faster in the fragile soil conditions of subtropical Brazil and Argentina, where dramatic reductions in soil erosion and improvements in soil quality and moisture retention have been observed from the practice. In the dry, variable moisture conditions of many parts of Africa, additional soil moisture and improved soil quality will translate into extra yield. In addition production will be more sustainable because land will not have to be abandoned due to excessive erosion and infestation with speargrass (*Imperata cylindrica*), which moves into eroded land. No-till combined with fertilizer use will sustain soil productivity and reduce the need to clear new land after the old is abandoned. The mulch of crop residue and dead weeds reduces germination of weeds in the crop. This makes it easier for farmers to control weeds manually. The mulch plus a cropping pattern of maize grown in rotation with legumes (soybean, cowpea, and *Muccuna* spp.), should lead to improvements in soil organic matter content, structure, and fertility of soil, along with higher yields.

Table 3. Total amounts of water runoff and soil erosion from conventional and no-till systems in an Iowa (USA) small watershed under natural rainfall, 1973–1975.

Year	Tillage treatment	Water runoff (m^3/ha)	Soil erosion (t/ha)
1973	Moldboard plow	40,860	19.8
	No-till	21,972	1.36
1974	Moldboard plow	81,906	62.8
	No-till	37,961	2.2
1975	Moldboard plow	34,969	20.9
	No-till	31,977	4.4

Source: Baker and Johnson 1979.

Exciting results were also obtained with reduced tillage in irrigated rice in Senegal. Normally, farmers plow and then disc two or more times to kill the weeds and prepare a seedbed for transplanting. Pre-planting weed control with Roundup Dry Herbicide allows seedbed preparation with only one disking, thus eliminating one plowing and one or more diskings. In a number of trials undertaken by the Institut Sénégalais de la Recherche Agronomique and in demonstrations supervised by Winrock International, savings in input cost and labor were realized (table 4).

Farmers will have lower input costs due to elimination of plowing and one disking. This in turn saves labor and equipment. Good pre-planting weed control with Roundup

Table 4. Cost of conventional tillage and reduced tillage in rice in Senegal, demonstration trial, 1994.

	Cost ($/ha)	
Operation	Conventional	Reduced
Spraying	–	2.00
Plowing	72.50	–
Roundup Dry (26 sachets/ha)	–	72.00
Disking[a]	62.00	31.00
Total	134.50	105.00

Source: Winrock International, Senegal, and Institut Sénégalais de la Recherche Agronomique.

a\ Disking twice in conventional tillage and once in reduced tillage.

Dry herbicide provides more consistent crop weed management and allows planting at the optimum time, which lead to better and more consistent yield as demonstrated at two sites in the Senegal (table 5).

In farmer-scale tests in the Casamance region of Senegal, the average yield increase from reduced tillage compared with conventional tillage was 700 kg/ha ($112/ha). This is consistent with the results from the Senegal River region.

Adoption of No-till

In Ghana, no-till crop production with Roundup Dry herbicide has been adopted on about 650 hectares; additional area has been treated with the flowable formulation. The area in no-till is expected to grow substantially by 2000. We believe that a successful model has been established in Ghana for development and introduction of no-till. In the first year, trials were undertaken by the Crops Research Institute (CRI) to establish optimum dose rates and application timing for Roundup Dry and to establish the agronomic needs for no-till planting. The basic recommendations from the work by CRI were then evaluated under practical farming conditions by smallholders under the direction of CRI and SG 2000.

Table 5. Yield (t/ha) of rice in reduced tillage compared with conventional tillage in the Senegal river region, small plot trials, 1994.

Operation	Site 1	Site 2
Conventional tillage	2.96	3.47
Reduced tillage[a]	4.38	4.54
Difference	1.42	1.07
Value at $160/t	$226	$172

Source: Winrock International, Senegal, and Institut Sénégalais de la Recherche Agronomique.
a\ Roundup Dry applied at 26 sachets/ha.

Involving the extension service at all phases of this development is critical to successful adoption. To help promote adoption on a broad scale, Monsanto's distributor in Ghana has employed a demonstrator who works closely with the CRI, extension service, and SG 2000 to teach the management skills required for no-till. These skills include calibration and use of knapsack sprayers to apply the herbicide to control vegetation prior to no-till planting.

Skills to handle differing conditions will also be necessary. For example, reclamation of land from heavy infestations of speargrass with Roundup Dry followed by no-till will require different management methods than no-till in established cropland. Heavy infestations of speargrass harbor insects and rodents, so it may be necessary to delay planting for 10 to 14 days after spraying Roundup and to treat the seed with an insecticide.

We plan a similar introduction in Senegal. The Ghana model will form the basis for no-till development at smallholder level in other countries of Africa.

Conclusions

Technologies such as no-till and reduced tillage, which can contribute much to sustainable agricultural production in Africa, can be successfully implemented at smallholder level. Critical aspects of support for the new technology are:

- Cooperative development and technical support involving local public (research and extension) and private sector and nongovernmental organizations
- The employment of local technicians to demonstrate the technology and support extension efforts

- An adequate distribution system that enables farmers to acquire the herbicide needed and to purchase or rent knapsack sprayers for applying the herbicide
- Availability of credit at both the distribution and farmer level

Nongovernmental organizations such as SG 2000 and Winrock International have proven to be excellent organizations through which to accomplish these objectives. Access to their cooperative village base and their experience in introducing basic technologies at smallholder level has been invaluable. In addition they develop strong relationships with local research institutes and the extension service, which is key to the sustainability of technology adoption.

It is, however, important for large donors to support other infrastructural developments in these countries. Farmers will not be motivated to produce more than their families can consume if their production cannot find its way to the large cities where it is needed. In addition it is critical that these farmers make a profit from their production to support the purchase of inputs for the following year's crop. Subsidized imports and food aid often compete with local production. Subsidized imports are a wasteful use of scarce foreign exchange, and foreign aid is increasingly unreliable as crop surpluses in developed countries shrink. It is therefore urgent for Africa to adopt technologies that will increase crop production, protect soil, and raise labor productivity.

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Soil Fertility Replenishment in Africa: A Concept Note

Pedro A. Sanchez, Anne-Marie Izac,
Isabel Valencia, and Christian Pieri

In tropical Asia, rising per-capita food production has largely been based on the adoption of strategic research results of germplasm improvement and accompanying agronomic and irrigation technologies in high-potential areas with enabling policy environments. Introduction of such practices was successful partly because of the high native fertility of most of the soils used for paddy rice and wheat production in Asia.

Similar approaches in tropical Africa have had limited impact. One reason is that soil fertility depletion, rather than poor crop germplasm, is the main biophysical limiting factor in the majority of African small farms. Coupled with Africa's limited potential for irrigated agriculture, strategic research in most of the continent has yet to come to grips with the main biophysical limiting factor at an appropriate scale. About 5 years ago, the Rockefeller Foundation decided to focus on overcoming soil fertility constraints of smallholder farms in Africa. Events since then have shown once more the vision of this institution in identifying key issues. The foundation's program, however, has concentrated on applied soil fertility research and its socioeconomic implications. While such efforts are invaluable at specific locations, properly focused strategic research is needed for a continent-wide effort.

This note proposes a new conceptual approach—the replenishment of soil fertility—and outlines the elements of a collaborative research program for tackling this issue within the socioeconomic and policy contexts of smallholders in sub-Saharan Africa.

The Problem

Soil fertility depletion in smallholder farms is the fundamental biophysical limiting factor responsible for the declining per-capita food production of sub-Saharan Africa. The magnitude of nutrient mining is huge. We estimate the net per-hectare loss during the last 30 years to be 700 kg N, 100 kg P, and 450 kg K in about 100 million hectares of cultivated land[1]. These figures are the balance of nutrient inputs, including fertilizers, minus nutrient outputs, which are primarily crop harvest removals. In contrast, commercial farms in North America and Europe have averaged net *positive* nutrient balances on the order of 2,000 kg of N, 700 kg of P, and 1,000 kg of K per hectare during the last 30 years in over four times the cultivated land, often resulting in groundwater and stream pollution. (Frissel 1978). Nutrient mining in sub-Saharan

[1] Calculated from Smaling 1993.

Pedro Sanchez is Director General and **Anne-Marie Izac** is Resource Economist at the International Centre for Research in Agroforestry, Nairobi. **Isabel Valencia** is Agronomist, Africa Region and **Christian Pieri** is Soil Scientist, Agriculture and Natural Resources, World Bank, Washington, D.C.

Africa, therefore, contrasts sharply with nutrient capital buildups in temperate regions.

How did this situation come about? Everywhere in the world, people have settled first in high potential areas with fertile soils, adequate rainfall, and moderate temperatures. In Africa examples are parts of the highlands of Eastern and Central Africa and the plateau of southern Africa that have soils derived from basic rocks. Population densities in areas such as the Lake Victoria basin are among the highest in the world. Originally such populations were supported by the high soil nutrient capital. This capital has gradually been depleted—nutrients lost through crop harvest removals, leaching, and soil erosion were not sufficiently compensated for by nutrients returned to the soil in crop residues, manures, and inorganic fertilizers. A similar situation now is occurring in the inherently less fertile soils of the West African humid savannas and the Sahel because of population growth.

Several decades of nutrient depletion have transformed originally fertile lands into infertile ones where cereal crop yields are less than 1 t/ha. In long-term trials in Kabete, Kenya, fertile red soils lost half their organic nitrogen and phosphorus contents in 15 years of continuous crop production without nutrient returns (Swift et al. 1994). In less fertile soils the process is faster and starts from a lower base.

In addition to causing marked crop productivity declines, nutrient depletion has other negative consequences for farm livelihoods including less fodder for cattle, less fuelwood for cooking, smaller amounts of crop residues, and less manure from the cattle. These effects increase runoff and erosion losses because there is less plant cover to protect the soils.

There are also major negative side effects outside the farm. Erosion, particularly in steep areas, causes silting of reservoirs and of coastal areas and in some cases leads to eutrophication of rivers and lakes. Food shortages and famines become more acute during drought years. Land fragmentation, due to local population growth rates that far exceed the national average, pushes people off the land and into urban areas where many are unemployed, further taxing the limited urban infrastructure. Unemployment, crime, and political unrest sometimes follow. This situation is typical in high-potential areas of Eastern and Southern Africa, particularly in Kenya, Uganda, Ethiopia, Rwanda, Burundi, Eastern Zaire, Tanzania, Malawi, Zambia, and Madagascar, as well as in Nigeria and other West African states. Dwellers in the capitals of many of these countries know these problems too well. The catastrophic civil wars in Rwanda and Burundi have land depletion and land scarcity as an underlying cause.

The Concept of Nutrient Capital

Nutrient capital can be defined as the stocks of nitrogen, phosphorus, and other essential elements that become available to plants in the medium term, say 25 years. Soils vary widely in their initial levels of nutrient capital, but all suffer depletion of that capital when brought into cultivation. Inherently fertile soils have high levels of nutrient capital, and the depletion process may not affect crop yields for decades. This is the case in the fertile red soils (Nitisols and Alfisols) of the African highlands. Inherently infertile soils, because of their low nutrient capital, are quickly depleted in a few years. This is typical of sandy soils of West Africa and southern Africa.

Fertilizer use is the traditional way to overcome soil fertility depletion, and indeed it is responsible for a large part of food production increases in Asia, Latin America, and the temperate regions, as well as in the commercial farm sector of Africa. Fertilizer use is viewed as a recurring cost of production, which must be paid for by the increased crop yields farmers obtain. Attempts to introduce this approach to smallholder farming in Africa have met with limited success even with input subsidies. Current thinking on natural resource management, however, leads us to propose an alternative approach for situations where the traditional one has not worked.

The basic resources plants use are light, water, and nutrients. Development activities such as reservoirs and irrigation systems that supply water for agriculture have long been considered a capital investment, paid for by governments and development banks. Users pay the recurrent costs such as maintenance of canals and drainage ditches on the farm. Replenishing plant nutrients can also be viewed as a capital investment. Restoring nitrogen and phosphorus, the two most limiting nutrients, to their original levels in the soil, in a way that maintains them and allows them to be used for many years, is a capital investment. Replenishment is not feasible with nutrients that are easily lost from the soil such as potassium, but mechanisms exist to build up the nitrogen and phosphorus capital of soils in which these elements have been depleted. The "interest" from such capital is used for crop production for years, and with good management, the "principal" can remain at a high level. Nitrogen and phosphorus, however, behave differently in terms of replenishment strategies.

Nitrogen

Capital nitrogen consists of the active and slow pools of soil organic nitrogen. Plant-available nitrogen comes from several sources: the mineralization of soil organic nitrogen pools, nitrogen fertilizers, and the decomposition of organic inputs such as plant biomass and animal manures. Biological nitrogen fixation becomes an input when the leaves of nitrogen-fixing species that have been added to the soil begin to decompose.

The decline of capital nitrogen also involves decreases in the quality of soil organic matter and in soil biological activity. This results in lower population and diversity of soil organisms (bacteria, fungi, earthworms) that mediate the release of nutrients from soil organic matter.

Virtually no research has been conducted in sub-Saharan Africa, or anywhere in the tropics, on how the process of soil depletion affects the quality of soil organic nitrogen and belowground biodiversity. Nonetheless, the replenishment of soil nitrogen will likely increase both the quality and quantity dimensions.

The recovery by crops of leguminous leaf nitrogen incorporated into the soil is about the same as the recovery from fertilizer nitrogen (20 to 50%). Organic inputs, however, have an important advantage over inorganic fertilizers in building up nutrient capital. Much of the remaining 50 to 80 percent of the applied organic nitrogen not utilized by crops is incorporated into active pools of soil organic matter because these organic inputs also provide the carbon needed as energy for microbial immobilization. Rapidly available carbon is often low in nutrient-depleted soils, and microorganisms need a carbon substrate to form soil organic matter. Inorganic fertilizers do not contain such carbon sources. Therefore, most of the fertilizer nitrogen not used by crops is subject to leaching and denitrification losses, while much of the nitrogen released from organic inputs that is not utilized by crops will be "saved" as soil nitrogen capital.

The slow accumulation of soil organic nitrogen with organic inputs will make a difference in terms of long-term sustainability. This replenishment strategy is not new; it has been used for centuries in temperate-region agriculture that involves crop rotations and winter leguminous cover crops. What is new is the potential to do something similar in the tropics in a way that fits the circumstances of smallholder farmers. A couple of examples illustrate the potential of this strategy.

Improved Fallows

The vast subhumid plateau of southern Africa is a tropical savanna locally known as *miombo* woodlands. It is characterized by a rainy season lasting 4 to 6 months, followed by a long dry season. The average elevation is 1,000 meters, annual rainfall is 1,000 millimeters, and the soils are of medium to low potential. Typically, farmers grow maize during the rainy season and little during the dry season. Grass fallows 1-year to 5-years old coexist with maize cultivation. Maize responds strongly to nitrogen fertilizers, but few farmers have been able to afford the recommended rates since the elimination of fertilizer subsidies under the structural adjustment programs prevailing in most countries of southern Africa. Frequent dry periods during the rainy season or delays in the start of the rains often decimate crop yields. Diagnostic studies have found that nitrogen depletion, lack of fuelwood, and lack of dry-season fodder are the main constraints perceived by farmers in the *miombo.*

The problem suggests investigating the use of leguminous fallows to add nitrogen and release it to the soil, to smother weeds, and to improve soil physical properties. Work done by ICRAF and collaborators in Chipala, Zambia, has demonstrated that 2-year old *Sesbania sesban* fallows doubled maize yields over a 6-year period (2 years of sesbania followed by 4 years of maize) in comparison with continuous, unfertilized maize production for 6 years. This was accomplished in spite of the 2 years without maize production while sesbania was growing (Kwesiga and Coe 1994). Sensitivity analysis indicates that 2-year fallows maintain their economic superiority over continuous, unfertilized maize under all realistic assumptions, including one or two drought years at any time and fluctuations in maize, fuelwood, labor prices, and discount rates (Place, Mwanza, and Kwesiga 1994). In other words, enhanced biological nitrogen fixation does overcome nitrogen limitations to maize crops. In addition, we expect most of the nitrogen not taken up by the crop to build up capital nitrogen, but this needs to be measured.

Deep Nitrate Capture

Another important component in replenishment of soil nitrogen is the utilization of untapped subsoil nitrogen through management practices that increase the volume of soil exploited by plant roots. Recent research by ICRAF in western Kenya indicates that long-term cropping with annuals can result in accumulation of nitrate nitrogen in the subsoil, where it cannot be reached by the shallow roots of annual crops (Hartemink et al. forthcoming). A rotation of annual crops with short-duration fallows containing deep-rooted perennials holds promise as a way to utilize and recycle the subsoil nitrate that would otherwise be unavailable to crops. The magnitude of this "new" nitrogen resource is on the order of 100 kg N/ha per year in western Kenya. This source needs to be assessed in other soils, particularly those that have subsoils rich in iron oxides, which provide anion exchange sites that hold nitrate ions. There are 260 million hectares of such soils in Africa. Assuming that one-third of them are potentially arable, the magnitude of this resource is on the order of 9 million tonnes of nitrate nitrogen. The utilization of this hitherto unrecognized nitrogen source via its capture by deep-rooted perennials is an exciting area of research in improved fallow systems throughout sub-Saharan Africa.

We hypothesize that the use of such organic inputs can replace fertilizer nitrogen applications in maize at the 4 t/ha grain yield level. At high yield levels comparable to those of commercial farms in the developed world, say 7 t/ha, organic nitrogen inputs are insufficient and must be supplemented by inorganic fertilizers (Sanchez 1995). The interactions between organic and inorganic sources of nutrients is essentially a new subject of research. Little is known about it because previous research has mainly compared one type of source with another. Also, the importance of enhanced biological nitrogen fixation in these systems relative to other potential processes for the replenishment of soil nitrogen, such as utilization of subsoil nitrogen not tapped by crops, nitrogen fertilization, and the recycling of nutrients through plant residues, is not known. The process of soil nitrogen replenishment, per se, needs to be investigated, quantified, and modeled in different soils under different management practices.

The replenishment of soil nitrogen therefore is a process of gradual build-up. The replenishment of soil phosphorus involves a different approach.

Phosphorus

The main sources of plant-available phosphorus are the weathering of soil minerals, the mineralization of soil organic matter, fertilizers, and organic inputs. Phosphorus, unlike nitrogen, is not biologically fixed from air, and the phosphorus content of plant residues and manures is normally insufficient to meet crop production requirements. In many African soils, sustainable crop production is impossible without application of phosphorus fertilizers.

Organic inputs, therefore, cannot supply most of the phosphorus required by crops. Deep capture of phosphorus is likely to be negligible due to the very low concentration of available phosphorus in the subsoil. When improved fallows and green manures accumulate phosphorus in their biomass and return it to the soil via litter decomposition, that is, recycling, it does not constitute an input from outside the system. The shortage of available soil phosphorus is compounded by the physiological fact that most of the phosphorus accumulated by cereal crops and grain legumes is in the grain and is thus removed from the field at harvest. The proportion of phosphorus recycled back to the soil in basic grain crops, assuming complete crop residue return, is on the order of 38 percent. Comparable figures for other nutrient elements are higher—54 percent for nitrogen and 89 percent for potassium (Sanchez and Benites 1987). Therefore, phosphorus is often the critical nutrient in nutrient-depleted soils of Africa.

Soils in fields that receive a realistic amount of leguminous mulches, say 4 t/ha of dry matter, receive 8 to 12 kg P/ha annually. This about half of the phosphorus requirements of a maize crop yielding 4 t/ha of grain, which accumulates 18 kg P/ha. Therefore, inorganic sources of phosphorus must be applied to cropping systems in soils depleted of this element (Palm 1995). The strategy is to utilize all the available organic sources first, including manures, and to supplement the difference with phosphorus fertilizers. Interactions between organic and inorganic sources of phosphorus also need to be quantified.

In soils that have high capacity to fix (make insoluble) phosphorus by iron and aluminum oxides, a different strategy is possible. Such soils can be identified as having red clay topsoils, and they cover millions of hectares of Africa including many of the nutrient-depleted farmed areas. Large, one-time applications of phosphorus fertilizers could quickly replenish the phosphorus supply of these soils. The "fixed" phosphorus will be gradually released to plants for 5 to 10 years by release from the oxide clay surfaces.

Techniques to facilitate the replenishment of soil phosphorus, in addition to fertilization include the effective use of available organic sources, the maintenance of soil biological activity and biodiversity of soil organisms (e.g., mycorrhiza). The integration of available organic resources with commercial phosphorus fertilizers may be the key to increasing the plant availability of the fertilizer phosphorus. Preliminary research in western Kenya indicates that plowing in *Tithonia diversifolia*, a common shrub on farm borders, along with triple superphosphate increases the effectiveness of added phosphorus. Possible explanations remain speculative but may include the solubilization of fertilizer phosphorus and desorption of fixed soil phosphorus. Because research in sub-Saharan Africa has largely ignored the integration of organic materials with phosphorus fertilizers, little is known about the influence of organic materials on phosphorus solubilization and sorption-desorption.

The replenishment of soils highly deficient in phosphorus requires use of phosphorus from external resources. A one-time application of large quantities of rock phosphate, which slowly releases plant-available phosphorus for several years, is one promising strategy for phosphorus-deficient soils with high phosphorus-fixing capacity. Rock phosphate deposits exist throughout Africa, but they vary in their effectiveness as fertilizers. Some are of high quality, like those in Madagascar and Tanzania, while others, like those in Uganda, are not.

Experience during the last 20 years in similar soils of the Cerrado region of Brazil has shown that large applications of phosphorus can build the fertility of the soil in a few years and that the residual effect of such build-ups lasts for 5 to 10 years. These corrective applications plus an enabling policy environment revolutionized farming in the Cerrado, which is now a major food-exporting region (Lopes 1983). Brazilian farmers used phosphorus as a capital investment on a large scale.

Making Replenishment Operational

Soil fertility replenishment is likely to result in a number of positive external benefits associated with enhanced crop production, increased coverage of the soil surface with vegetation, and increased soil biological activity. For instance, enhanced plant growth and root development in the subsoil might result in enhanced sequestration of carbon in the soil and reduced losses of nitrogen by leaching. No data are available to quantify these potential benefits, although preliminary data from Kenya indicate overcoming phosphorus deficiency can lead to a reduction in the levels of leachable soil nitrate. Increased coverage of the soil surface with vegetation might result in reduced soil erosion and the enhancement of soil biological activity might result in maintenance of biodiversity of belowground fauna and flora. Data are urgently needed to quantify these externalities.

The soil conservation dimension of many agroforestry systems ensures that nutrient inputs added through biological nitrogen fixation, deep nutrient capture, or application of phosphorus fertilizers are not lost through runoff and erosion. A phosphorus investment program that does not include contour hedges or other erosion-control technologies is likely to do more harm than good, because the phosphorus-rich topsoil can be eroded away and deposited in stream banks.

The various benefits of soil fertility replenishment are to be felt at different geographical scales, on-farm, national and global. The issue of who should pay for these investments thus becomes relatively straightforward, in theory at least. Using the fundamental principle that those who benefit from a course of action should incur the costs of its implementation, three layers of costs can be distinguished, corresponding to the three layers of benefits. On-farm maintenance costs should be borne by farmers, whereas the national and global societies should share the more substantial costs of actual phosphorus applications. Thus, sharing should reflect the ratio of national to global benefits. Research is needed for evaluating these various layers of costs and benefits on the basis of actual field measurements.

Strategic biophysical and socioeconomic research is needed to make this concept widely applicable in Africa. The strategic nature of the research is two-fold—it has never been attempted before, and research elucidating the principles and basic process at key locations in contrasting soils in Africa will provide the basis for continent-wide extrapolation. A consortium on national research institutions, international research centers, and nongovernmental organizations should be constituted to tackle this issue.

Full on-site evaluation of environmental externalities such as soil conservation, carbon sequestration, biodiversity conservation, improved rural economies, and less migration to urban areas should form part of the research strategy.

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ROW TO 3 FEMALE ROWS

Mobilizing Science and Technology for a Green Revolution in African Agriculture

Norman E. Borlaug

It is a pleasure to attend this workshop to explore policies and strategies to achieve greater impact from investments in agricultural research and technology generation in Africa. I am now in my 51st year of continuous involvement in food production programs in developing nations. During this period, I have seen much progress in increasing the yields and production of various crops, especially the cereals, in many food-deficit countries. Clearly, the research that backstopped this progress has produced huge returns.

Yet, even though the world food supply has more than tripled during the past three decades, the so-called Green Revolution in cereal production has not solved the problem of chronic undernutrition for hundreds of millions of poverty-stricken people around the world who are unable to purchase the food they need, despite its abundance in world markets. No region has been more bypassed in the Green Revolution than sub-Saharan Africa. High rates of population growth and little application of improved agricultural technology have resulted in declining per capita food production, escalating food deficits, and deteriorating nutritional levels, especially among the rural poor.

Poets—and city folk—love to romanticize agriculture, portraying it as some sort of idyllic state of harmony between humankind and nature. How far this is from the truth. Since Neolithic women domesticated our food crop species 10,000 to 12,000 years ago, agriculture has been a battle between the forces of natural biodiversity and the need to produce food under increasingly intensive production systems. Yet through advances in science—mainly during this century—world food supplies have increased more rapidly than population, and in general, have become more reliable.

World population will grow by nearly 1 billion people during the 1990s and then again by another 1 billion people during the first decade of the twenty-first century. A medium projection is for world population to reach 6.2 billion by the year 2000 and about 8.3 billion by 2025, before, it is hoped, stabilizing at about 10 billion toward the end of the twenty-first century.

Had the world's food supply of 4.6 billion gross tonnes been distributed evenly in 1990, it would have provided an adequate diet (2,350 calories, principally from grain) for 6.2 billion people—nearly 1 billion more than the actual population. However, had the people in Third World countries attempted to obtain 30 percent of their calories from animal products—as in the USA, Canada, or European Union countries—it would have been possible to sustain a world population

Norman E. Borlaug is President, Sasakawa Africa Association.

of only 2.5 billion people—less than half of the present world population.

At least in the foreseeable future, we will continue to rely on plants, and especially the cereals, to supply virtually all of the increased food demand. Even if current per capita consumption remains unchanged, population growth would require that world food production increases by 2.6 billion gross tonnes, or 57 percent, between 1990 and 2025. However, if diets improve among the hungry poor, estimated to be 1 billion people, living mainly in Asia and Africa, world food demand could increase by 100 percent—to 9 billion gross tonnes—over this 35-year period. And we have to achieve this production increase in environmentally sustainable ways!

Africa's Agricultural Development Challenge

Unless recent production trends are drastically altered, sub-Saharan Africa will be producing less than 75 percent of its food requirements by the year 2000. While some economists claim that growing dependence of African nations on imports to meet food demand is not necessarily a problem, I beg to differ, at least at the present stage of development in most nations. How will the low-income African nations finance and distribute these imports? And how will the poor afford to purchase this imported food?

Sub-Saharan Africa's extreme poverty, poor soils, uncertain rainfall, increasing population pressures, changing ownership patterns for land and cattle, political and social turmoil, shortages of trained agriculturists, and weaknesses in research and technology delivery systems all make the task of agricultural development more difficult. But we should also realize that to a considerable extent, the present food crisis is the result of the long-time neglect of agriculture by political leaders.

Even though agriculture provides the livelihood for 70 to 85 percent of the people in most African countries, agricultural and rural development have been given low priority. Investments in distribution and marketing systems and in agricultural research and education are woefully inadequate. Furthermore, many governments pursued and continue to pursue a policy of providing cheap food for the politically volatile urban dwellers at the expense of production incentives for farmers.

Despite the formidable development challenges in Africa, the elements that worked in the industrialized nations, Latin America, and Asia will also work there. If effective seed and fertilizer supply and marketing systems are developed, the nations of sub-Saharan Africa can make great strides in improving the nutritional and economic well-being of their desperately poor populations.

There has been so much misinformation spread about the Green Revolution in Asia that it would take days to clear the air on what it was and wasn't. To me, the Green Revolution was the beginning of a process of applying science to Third World agricultural production. The introduction of yield-increasing, cost-reducing technology in Asia clearly improved the economic well-being of farmers—large and small. But the greatest beneficiaries have been consumers in the developing world, who have enjoyed a steady decline in the real cost of food over the past 25 years, which is an especially important benefit for the poor. This lesson must not be lost on Africa.

In addition to the potential to improve yields on the best existing farmlands through the introduction of higher yielding seed-fertilizer technologies, sub-Saharan Africa—unlike Asia—still has large tracts of unused land that eventually can be brought under the plow. However, the lack of power—animal or motorized—to bring these uncultivated lands into production has been a major constraint. The expansion of animal traction has been limited historically by animal-health problems, such as trypanosomiasis transmitted by the tsetse fly throughout the forest zones of tropical Africa and East Coast fever transmitted by ticks in East Africa. A much more concerted effort is needed to control these diseases so that animal traction can expand the size of peasant farms from the 1 to 2 hectares at present to 5 to 10 hectares, which is a more viable economic unit. Indeed, even doubling and tripling yields on a 2-hectare farm will not provide adequate family income to improve standards of living significantly.

Nigeria's former Head of State, Olusegun Obasanjo—himself a farmer—has identified the crux of Africa's agricultural development challenge:

> As long as farming remains, at best, marginally rewarding, young men and women will drift away from the rural areas to increase the battalions of the urban poor. The idea, therefore, that African agriculture should be based on a half hectare holding is, to say the least, unappetizing. I want to see the evolution of young, emergent, commercial farmers who will be holding not half a hectare of land, but 5 to 10 to 20 hectares of land, and for whom the city will have no big attraction.

Tackling the Soil Fertility Management Issue

Without doubt the most important factor limiting crop yields in developing nations worldwide—and especially among poor farmers—is soil infertility. This problem is especially acute in much of sub-Saharan Africa and in the highland areas of Latin America and Asia.

Many of the lowland tropical environments—especially the forest and transition areas—are fragile ecological systems, where deeply weathered, acidic soils lose fertility rapidly under repeated cultivation. Traditionally, slash-and-burn shifting cultivation and complex cropping patterns permitted low-yielding, but relatively stable, food production systems. Expanding populations and food requirements have pushed farmers onto more marginal lands and also have led to a shortening of the bush-fallow periods previously used to restore soil fertility. With more continuous cropping on the rise, organic material and nitrogen are being rapidly depleted while phosphorus and other nutrient reserves are being depleted slowly but steadily. This is having disastrous environmental consequences, such as serious erosion and weed invasions leading to impoverished fire-climax vegetation.

Unless soil fertility is restored in these areas, farmers will gain little benefit from the use of improved varieties and more productive cultural practices. Soil fertility can be restored effectively by applying the right amounts of the right kinds of fertilizer—either chemical or organic or, preferably, a combination of the two—according to the requirements of different crops, soil types, and environments.

Of course, scientists, extension officers, and farmers should strive to attain better efficiency in fertilizer nutrient use. In particular, where intensive cropping is practiced, improved monitoring of secondary nutrients and minor element deficiencies is needed to increase crop yields and to reduce fertilizer costs. But we should forget that as much as 50 percent of the increase in crop yields worldwide during this century is due to the adoption of chemical fertilizers. In the future, integrated soil fertility management strategies can reduce wasteful fertilizer use and should be encouraged.

I am convinced that the most environmentally friendly action that can be taken in sub-Saharan Africa—given available knowledge and technology transfer possibilities—is to promote moderate and proper use of chemical fertilizers in an aggressive manner. Increased chemical fertilizer use should help to reduce soil erosion by increasing plant biomass and vegetative ground cover and, assuming that crop residues are returned to the soil, contribute to improving the organic matter content of the soil.

Sadly, this view is not in fashion these days. A common assumption among some environmentalists, social scientists, and a few agricultural researchers—especially those from privileged countries—is that the next step for small-scale Africa farmers toward improving soil fertility and crop production is to introduce so-called low-input technologies. Over time, the argument goes, Africa's resource-poor farmers will reach the point where they can adopt modern technologies involving the use of purchased inputs.

While such low-input approaches have some appeal, they nonetheless have serious drawbacks. An important one is that low-input technologies often turn out to be knowledge-intensive, requiring that farmers possess more than the ordinary skills in crop management. A further prerequisite is that levels of literacy be raised in rural communities. Until this happens, few of the so-called environmentally friendly technologies now available—such as use of new crop rotations, organic manures and crop residues, and integrated pest management—are likely to spread very far beyond research stations.

There is a message for Africa in the decisions made to invest heavily in chemical fertilizer by China—the most skillful efficient and extensive user of organic fertilizer—and also for those poorly informed environmentalists and neo-agriculturists who believe that if all of the organic wastes, animal manures, human excrement, and crop residues were used as fertilizer, the world could produce all the food needed without the use of chemical fertilizer. The ill-founded faith by some influential individuals that organic fertilizers alone can provide the plant nutrients to revolutionize agricultural production in sub-Saharan Africa is misleading policy makers and contributing to a worsening of per-capita food availability in most African countries. There simply is not enough organic fertilizer available to provide sufficient nutrients to the soil to satisfy the growing food demand of Africa. Moreover, there is competition for animal manure, which is also dried and used as a cooking fuel.

We must also acknowledge that in many of the most productive areas—especially the warm irrigated areas—there are problems of soil erosion and declining water quality, which, if left unchecked, can lead to the permanent loss of prime agricultural land. In most cases, the root causes of this environmental degradation have been inadequate investments (especially in drainage systems in irrigated areas) and mistaken economic policy—not modern, science-based technology. Low profits (mainly in developing countries) have kept farmers from investing as they should in resource conservation, while excessive subsidies (mainly in industrialized countries) sometimes have caused overuse of agricultural chemicals, with consequent environmental damage.

Yet the message of the 250,000 small-scale farmers who have been involved in the Sasakawa-Global 2000 program is that they are loath to settle for "low input, low-output" technologies since they do not reduce the human drudgery of farming nor reduce the prospects for hunger and poverty. However much they may respect traditional farming practices, agricultural scientists must resist the temptation to romanticize them. They must not succumb to the illusion that—confronted with explosive population growth—Africa's food needs can be met through the so-called "improved low-input sustainable" systems that are based largely on improved traditional practices that require much more from farmers in terms of labor, knowledge, and skill.

Keeping Agricultural Science Relevant

The capacity to transmit agricultural research findings to the small-scale farmer is heavily dependent upon the technology transfer capacities of publicly funded international and national research and extension systems. While privately funded agribusiness is playing an increasingly important role in technology generation and transfer in a few developing countries, publicly funded efforts are still central components in any strategy to reach the small-scale farmer with improved food crops technology in sub-Saharan Africa.

Thus, any strategy to maximize investments in technology generation and transfer must find ways to fund—adequately and with stability—the international agricultural research centers and the national agricultural research systems. In recent years, the effectiveness of virtually all of the national research systems has been severely reduced by inflation and real budget cuts. The international agricultural research centers have also suffered financial setbacks, but not to the same magnitude as the national systems. Funding one without the other will not result in significant impact. Rather there is a need to jointly finance both levels and to maximize the potential from scientific networking between the researchers of the international centers and those of the national agricultural research systems. In particular, it is very important that outstanding national researchers have adequate funds to participate fully in international research networks.

One important international agricultural research center function is to serve as the hub of various research networks. In addition to research collaboration on specific problems, international center networking functions include germplasm and information exchange, which should include, I believe, a continuing program of practical in-service training for mid-career researchers from national programs as well as visiting scientist opportunities for senior-level visiting scientists.

The key point here is that for a research network to function properly there has to be lots of interaction between the members.

Even with all of the advances in information technology, there is a still a need for face-to-face contact. This means that national scientists need to visit the international centers with fair frequency while international agricultural research center scientists need to spend significant time visiting national program scientists and touring agricultural areas.

Although international and national agricultural scientists certainly have advanced the frontiers of knowledge over the past three decades, I believe their more significant contribution has been the integration of scientific knowledge and application in the form of improved technologies to overcome pressing crop production problems. This should continue to be the primary mission of these publicly funded institutions in the foreseeable future. Moreover, impact on farmers' fields and alleviation of rural poverty—rather than the number of learned publications—should be the primary measure by which to judge the value of the work of the international agricultural research centers and national agricultural research systems.

Unfortunately, agricultural science—like many other areas of human endeavor—is subject to changing fashions and fads, generated from both within the scientific community and imposed upon it by external forces, especially the politically induced ones that affect the actions of financial donors. In my own career, I have seen various scientific bandwagons come and go. In the 1930s and 1940s, plant improvement by the development of polyploid varieties (doubling of chromosomes) was promoted as the panacea. By the 1950s and 1960s, mutation genetics was the rage. In the 1970s and 1980s, anther culture, somatic tissue culture, and farming systems research were the craze. In the late 1980s and 1990s, biotechnology and genetic engineering, computer modeling of cropping systems, maximizing biodiversity, low-input sustainable agriculture, and participatory farmer research are now the terms in vogue.

Each of these lines of research has had some beneficial aspects. But all have had something else in common: their proponents, certainly partly driven by the desire to secure more research funds, have exaggerated the potential for benefits, especially in the near-term. Increasingly, I fear, the international agricultural research centers and national agricultural research systems are falling prey to scientific bandwagons that will not solve Third World food production problems.

From my perspective, research managers and decision makers in the international agricultural research centers and national agricultural research systems need to spend more time on the ground, monitoring what is happening—or not happening. Further, international agricultural researchers themselves must strengthen their interactions with national research and extension systems, and farmers. Too many have become detached from the realities in farmers' fields, preferring to measure their achievements by the information and products generated—and learned papers published—rather than by adoption of their technologies in the countryside. This should be changed.

Will the Private Sector Be a Panacea?

After three decades of disappointing performance by public-sector organizations in the developing nations, many people are now looking to the private sector for new leadership. Experience in other parts of the world has shown that private enterprise is more effective in delivering improved technology to farmers and in developing marketing and credit functions. Of course, governments must create a conducive and enabling regulatory environment for private entrepreneurs to mobilize the capital needed to develop vibrant agribusinesses and to ensure that healthy competition develops. This transitional period from state socialism to market-oriented economies requires political and social stability, adequate time, and big capital investments.

Notwithstanding its many virtues, we should also realize that privatization is not a panacea for all development activities and that there are many activities that the public sector must continue to undertake. In particular, most of the research and extension work for staple food crops, especially to serve small-scale farmers, will remain a public-sector activity. Therefore, improving the quality and orientation of public spending for agricultural research and extension can help greatly to raise the productivity of African producers.

Although large, self-serving, parasitic bureaucracies exist in other ministries, which are probably worse, we must face up to the fact that most ministries of agriculture are in need of far-reaching reorganization. Many of the previous functions under the canopy of ministries of agriculture, such as crop marketing boards, input supply, and various regulatory activities (e.g., obsolete plant and animal quarantine regulations), have been—or should be—significantly reduced, if not eliminated. Yet large numbers of personnel previously assigned to these activities frequently remain on the payroll. It is time for national leaders to stop considering ministries of agriculture as "employment agencies," and really begin to consider them as development agencies, and organize them accordingly.

While we may wish it wasn't so, the reality is that, given the size of budgetary resources, there are simply too many public-sector employees—many of them poorly trained—engaged in agricultural research, extension, and production activities. In all probability, the numbers of research and extension staff should be cut by one-third or more, with the resulting budgetary savings used to bolster the operational budgets needed to achieve impact. Of course, these smaller research and extension organizations will need much better-trained, well-motivated, and mobile staff.

The real hope for private contributions to agriculture lies in seed production, input delivery, equipment supply, output marketing, and financial services. Over time, successful seed producers and input suppliers will also invest in research and development activities. But in the short- and intermediate-term, the primary suppliers of research information and products for small-scale food producers will continue to be publicly funded institutions.

Confusion in Policy Circles

Robert Paarlberg (1994) has described succinctly the consequences of the debilitating debate between agriculturists and environmentalists about what constitutes so-called sustainable agriculture in the Third World. This debate has confused—if not paralyzed—policy makers in the international donor community who, afraid of antagonizing powerful environmental lobbying groups, have turned away from supporting science-based agricultural modernization so urgently needed in sub-Saharan Africa and parts of Latin America and Asia.

This policy deadlock must be broken. In doing so, we cannot lose sight of the enormous job before us to feed 8 to 10 billion people. We cannot turn back the clock, and we must also recognize the vastly different circumstances faced by farmers in different parts of the Third World and assume the appropriate policy postures. For example, in Europe or the U.S. Corn Belt, the application of 400 to 500 kilograms of fertilizer nutrients per hectare of arable land can cause some environmental problems. But surely, increasing fertilizer use in sub-Saharan Africa from 10 kilograms of nutrients to 30 to 40 kilograms per hectare of arable land is not an environmental problem but a central component in Africa's environmental solution.

The Professional Moral Responsibility of Scientists

Agricultural scientists and policy makers have a professional and moral obligation to warn the political, educational, and religious leaders of the world about the magnitude and seriousness of the arable land, food, and population problems that lie ahead. If we fail to do so in a forthright manner, we will be negligent in our duty and inadvertently will be contributing to the pending chaos of incalculable millions of deaths by starvation.

Twenty-five years ago, in my acceptance speech for the 1970 Nobel Peace Prize, I said that the Green Revolution had won a temporary success in man's war against hunger, which if fully implemented, could provide sufficient food for humankind through the end of the twentieth century. But I warned that unless the frightening power of human reproduction was curbed, the success of the Green Revolution would be ephemeral.

It seem to me that we have failed to educate policy makers about the strong positive linkages in the Third World between agricultural development, poverty reduction, and environmental protection. Without doubt, the reduction of rural poverty is a necessary condition, not only for broad-based economic development but also for improved resource conservation. As Richard Leakey correctly points out, "you have to have at least one square meal a day to be a conservationist or environmentalist."

The introduction of productivity-enhancing agricultural technologies is a win-win-win solution. Modern technology can increase farm incomes and simultaneously lead to lower real food prices, thus benefiting all consumers, especially the rural and urban poor. Agricultural development can also reduce environmental degradation, which is primarily rural- and poverty-based. With increased prosperity, farmers can afford to invest more in protecting their soil and water resources.

As I have come to learn something about African agriculture over the past 9 years, I must say that I am extremely frustrated between the clear capacity for quantum jumps in food production and agricultural productivity and the continuing failure to realize this potential. Permit me to make an analogy. At the moment of conception each human being is dealt a genetic hand of cards that represents his or her potential. The extent to which that this inherent potential is realized is determined by good nutrition, health, and education, among other factors. Although virtually none of us utilizes our full potential, those from the more affluent nations have a much better chance of realizing more of their potential than those who begin and suffer life in poverty, hunger, and poor health.

Africa is a continent of enormous agricultural potential. The bleak predictions of African famine, social chaos, and environmental destruction need not happen. Warm year-round temperatures and vast areas of potentially arable land are conducive to highly productive and environmentally sustainable agricultural systems. The challenge is to break out of this cycle of wasted human potential and help African farmers—and nations—rise up and achieve their full capacity.

Central to the solution is a concerted effort among national governments, international donor agencies, research and extension organizations, and the private sector to help small-scale farmers to break out of the vicious cycle of poverty and wasted potential that they currently endure.

At my age I am impatient. If I am to see a Green Revolution in Africa, it must happen soon. I believe that if a dramatic change takes place in food production in one country others will follow. In recognition of the late Ryoichi Sasakawa's desire to help millions of African people live better and happier lives, the remainder of my life shall be dedicated to this task.

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Science and Technology Policy for the Modernization of Agriculture

G. Edward Schuh

My original intent, and assignment, in preparing this final chapter was to synthesize and summarize the discussion at the final session of the conference. That proved to be too demanding a task. The issues raised in that discussion were wide ranging, and there were multiple perspectives on almost all issues raised. Consequently, I decided to address the topic of science and technology policy for the modernization of agriculture as a general issue. In its own way, that puts a proper fini to the conference because most of what we addressed for those few days was about science and technology policy, even though we didn't always discuss it in those terms.

For most countries the topic of science and technology policy is an important issue in its own right, in part because it is so badly neglected as a policy issue. The key to the growth of African economies, and to generating increases in per capita incomes in the future, will be the science and technology policies political leaders in the region design and implement. Yet the agendas of such policy makers tend to be dominated by macroeconomic policies to pursue important stabilization goals and by microeconomic policies to attain static efficiency goals, both on the recommendation of international development agencies and as conditions for receiving development assistance.

This chapter has three main parts. The first addresses the importance of science and technology policy. It attempts to answer the question of why policy makers should give more attention to this component of policy and how investments in science and technology contribute to important development goals. The second part addresses the various elements of science and technology policy. This material identifies the various dimensions of such policy and reviews the decisions policy makers face when dealing with it. The third part identifies some of the key issues policy makers need to address in developing an effective science and technology policy.

The Importance of Science and Technology Policy

It is difficult to overstate the importance of a sound science and technology policy if the countries of the subcontinent are to experience sustained economic growth and development in the decades ahead. The topic is broad in scope and includes the investments a society makes in its human capital generally, the investments it makes in agricultural research and extension, and the time and effort it expends in designing modern and effective institutional arrangements for guiding these various investments.

Science and technology policy is important because human capital is important. It is true that investments in physical infrastructure, in groves of trees and other perennials, and in livestock are critical elements of a broad-based

G. Edward Schuh is Dean and Professor, Humphrey Institute of Public Affairs, University of Minnesota, Minneapolis, and Chair, Agricultural Council of Experts, Sasakawa Africa Association.

development strategy. So are the physical structures needed for farming, for processing agricultural produce and transporting it to the consumer, and for producing modern inputs and transporting them to the widely dispersed farms. However, under a wide range of circumstances, investments in human capital, and especially in new knowledge, are the critical sources of economic growth and development. In fact, in the future an ever larger share of the increase in output in the economies of the subcontinent will be accounted for by investments in human capital.

A Broad-Based Source of Economic Growth

The introduction of new production technology into the agricultural sector produces economic growth and development that is broad-based and distributed in favor of the poor. It does this in multiple ways and on a scale that is not possible to achieve by concentrating the development effort on other sectors of the economy.

In the first place, if the new production technology is introduced in the production of subsistence commodities, or those that come under the rubric of widely consumed staples, the adoption of that technology will usually lead to a decline in the real prices of those commodities. For consumers, that decline in real price is equivalent to an increase in their real income. If the particular commodity is widely consumed in society, such as maize in sub-Saharan Africa, those increases in per capita income will be widely distributed. Even though the increase in per capita income may be relatively small for each individual consumer, when summed over the entire population, the total can be very large. That is why the social rates of return to investments in agricultural research have been so high—typically ranging from 35 percent to more than 100 percent.

The nature of the demand for food causes the modernization of agriculture through the introduction of new production technology to have another important and desirable effect. Low-income consumers spend a larger share of their income on food than do middle and upper income consumers. Thus, low-income consumers benefit in a relative sense from the introduction of new technology in the production of subsistence commodities. That is a highly desirable result; there are few other sectors of the economy for which that is the result of the modernization process.

Second, if the new production technology generated by research is tailored to export commodities or import-competing commodities, the initial effects of adoption will be different, but the ultimate effects will be similar. If the country is relatively unimportant in terms of the international market for the commodity being considered, there will be little tendency for the price of the commodity to decline as a consequence of the adoption of the new technology. However, the country will become more competitive compared with other countries participating in the market. For export commodities, the country's exports will tend to increase. For commodities that tend to compete with imports, imports will decline. Consequently, there will be an increase in foreign exchange earnings in the case of exports and a savings of foreign exchange in the case of import-competing commodities. These increased foreign exchange earnings (or savings) can be used to finance a higher rate of economic growth. Eventually, these effects will be widespread as well.

Third, broad-based increases in per capita income will induce a secondary wave of economic growth. Consumers will use their increased income to demand a wider range of consumer goods and services. This increased demand will induce a supply effect in the nonfarm sectors of the economy as new activities expand. This can have significant multiplier effects, eventually redounding to the agricultural sector itself.

In conclusion, there is no other sector of the economy in which development activities can have such a widespread effect, and which favors the poor relative to the middle and upper income groups. The reason for these unique effects is that everybody consumes food. The importance of developing the economy by focusing on the agricultural sector is rooted in this basic fact, rather than in the share of the labor force in agriculture or the share of the country's GDP from agriculture. The international development community is simply wrong when it cites the declining shares of these last two components of the economy as the basis for neglecting agriculture.

Competitiveness

Most countries of the subcontinent are opening their economies to the forces of international trade as a consequence of policy reforms designed to make more efficient use of their national resources. That raises important issues of international competitiveness. To remain competitive in international markets without experiencing a significant decline in its real exchange rate, a country needs to increase resource productivity in its export and import-competing sectors. The key to raising that productivity on a sustained basis is to invest in agricultural research and extension to produce and new production technology and diffuse it among the nation's producers. This increase in productivity is critical to earning the foreign exchange needed to finance a high rate of economic growth.

There is an important related issue. Political leaders in developing countries, and those in African countries are no exception, tend to complain about the decline in the external terms of trade they face in the international economy. That decline, when it occurs, is largely induced by the adoption of new technology in other countries. Defending against it has an obvious solution. The country can increase its own capacity to produce similar new technology and thus compete effectively. The increase in output from the same bundle of resources will offset the decline in relative price, without loss in revenue.

The alternative, of course, is to devalue the nation's currency. However, that leads to a decline in the standard of living for the country as a whole because it requires giving up an ever larger quantity of domestic resources to acquire the foreign exchange needed to service the foreign debt and to acquire the inputs and raw materials needed for economic growth. Unfortunately, far too many countries have chosen that policy option, to the great detriment of its citizens.

Inducing More Resources into the Sector

Expanding the output of food and agricultural commodities at a pace sufficient to accompany the increase in demand from rapid population growth, rising per capita incomes, and growth in trade will require that additional resources be induced into the sector. This is especially true if a net outflow of labor from agriculture begins to occur in response to the expansion of the nonfarm sector.

The production and diffusion of new production technology into agriculture can be an important means of inducing that inflow of additional nonlabor inputs. Moreover, it will induce an inflow of resources critically needed for output to expand. Improved fertilizer-responsive varieties, for example, will induce an increase in the use of commercial fertilizers and thus raise the productivity of land. Improved mechanization, adapted to local conditions, will lead to an inflow of capital in the form of machinery and capital, and thus raise the productivity of labor. Both of these processes will increase the demand for cognitive skills and other knowledge, thereby increasing the investment in education.

In conclusion, even though the introduction of new production technology may displace labor as a consequence of the decline in relative labor earnings that it brings about and thus the need to gain more remunerative earnings, it also provides the basis for inducing a shift of resources from the nonfarm sector to the farm sector to sustain an increase in output. This eventually leads to a more rational use of resources for the economy as a whole and helps set the stage for sustained economic growth and development.

Reducing Damage to the Environment

It is popular these days to condemn the use of modern production technology on the grounds that it causes damage to the environment. There are indeed many important issues here. Excessive use of commercial fertilizers can and does pollute both aboveground and belowground water supplies. Similarly, excessive use of chemicals to combat insects and diseases can contaminate the food on which it is used, as well as nearby water supplies.

On the other hand, new production technology can play an important role in reducing longer term damage to the environment. An important feature of many sub-Saharan countries is the expansion of agriculture up the sides of the hills and mountains and thus the emergence of serious soil erosion and the loss of productive topsoil. Production similarly expands onto marginal lands, where it also creates environmental damage and is thus unsustainable. In both situations, the population eventually has to move on, thus repeating the cycle.

One of the reasons for this expansion on the extensive margin is the lack of productivity-enhancing technology. This can best be seen by comparing what happened in the United States. Agricultural production has expanded almost steadily over the years, while at the same time over 40 million hectares of land have been taken out of production. This has occurred because of a sustained and significant increase in yields due to the introduction of new production technology. Had it not been for that new technology (or expansion on the intensive margin), agriculture in that country would also have expanded up the hills of Appalachia and the slopes of the Rocky Mountains, creating environmental damage of a high order.

The use of commercial fertilizers and chemicals has obviously been excessive in many places around the world. However, that need not be the case. As recent experience in the United States and elsewhere has shown, this new technology can be tamed and the damage to the environment reduced. Moreover, the objective of the research program can be precisely to reduce environmental damage, either by designing new ways of applying the modern inputs or by creating new production systems. The biological control of insects is an important example of just such a development. In the final analysis, the increase in productivity that new technology brings to agriculture reduces the demand on the underlying natural resource base and thus contributes to sustainable development over the longer term.

The Elements of Science and Technology Policy

The elements of science and technology policy are rooted in the production of new knowledge and the diffusion of that knowledge in the economy. On the surface, that sounds as if the problem is primarily one of investing in agricultural research and extension. However, that is far too simple a description of the decisions policy makers face in developing a sound science and technology policy. The new technology, for example, is for the most part imbedded in new production inputs, such as improved seeds, fertilizers and pesticides, and mechanical inputs. It also must be imbedded in the human agent if it is to be effective. And finally, highly qualified scientists and high-technology research equipment are needed in order for new production technology to be produced at a satisfactory rate. Each of these issues is discussed below.

Research

A useful way of identifying the main elements of a science and technology policy is to start at the core of the process, with those activities that produce new knowledge. New knowledge is produced in this context by research activities. It is important to note that research is an economic activity to be organized. If a nation has a cadre of research scientists available, the issue becomes how to organize them to conduct their research and thus to produce the new knowledge.

Limiting our discussion to agricultural research already raises a host of questions. For example, on which commodities should the researchers be concentrating? What are the problems or limitations that have to be addressed to ease the constraints facing producers? Is the main problem the lack of productive varieties? Or is the main problem deficiencies in the soils? Or is it a disease problem or an insect problem? And more generally, what is the proper mix between researchers and operating expenses? Should the researchers be doing applied research, basic research, strategic research, or a combination of the three? Should they be linked to the scientific community in other countries? Or should they work in isolation so as to specialize on the problems specific to their country?

These are all elements of science and technology policy viewed narrowly from the perspective of an ongoing research system. How well these decisions are handled will determine how efficiently the scarce resources allocated to research are utilized. It will also determine how productive the research system will be and thus the social rate of return to the investments in research. Despite these assertions, serious analysis to provide a more scientific basis for making these decisions is seldom undertaken, nor are the decisions themselves always taken as seriously as they might be.

One step removed from these important operational issues is another of equal or more importance. How many scarce resources should be allocated to agricultural research in the aggregate? We know that the social rate of return to investments in agricultural research is quite high—on the order of 35 to over 100 percent, as noted earlier. These tend to be far higher than the rates of return on investments in other social investments that policy makers tend to make. Typically, however, governments and policy makers grossly underinvest in agricultural research. The fact that the social rates of return are so high is strong evidence of such underinvestment.

Extension

Now, assume that we have a research system that is producing new knowledge and consider the next set of elements of a science and technology policy. The issue is how to get the new knowledge to the producers, and in an efficient way. It is generally accepted that an extension service is needed to do this, even when the literacy rate of the farmers is relatively high.

This raises questions about the kind of extension system to put in place. Should it be the World Bank's training-and-visit system? Or one patterned after the U.S. system? Or one designed to reflect local conditions? Similarly, should technical assistance to the farmer be part of the service? Or should the new knowledge be delivered by means of formal classes? Or in written material?

Again, all of these are organizational and institutional design issues. How well these questions are answered will determine how effectively the new knowledge will be diffused among the producers and what the overall productivity of the system will be. These will in turn affect the social rate of return to the use of scarce resources dedicated to these activities. As in the case of research, very little analysis and formal decision making typically go into these decisions. Decisions are made as much by habit—what was done in the past—as by any careful analysis of the particular situation.

Formal Schooling and Education

If one thinks about the typical extension program, the process can perhaps best be described as imbedding the new knowledge in the human agent. That is generally what the transmission of new production and cognitive skills is all about. But imbedding the new knowledge in the human agent implies the more general problem of formal education of the farmers and rural population. This is another important element of science and technology policy.

As in agricultural research, governments and policy makers tend to grossly underinvest in the education of farmers and the rural population more generally. The educational attainment of the rural population is typically well below that of the urban population. Moreover, even when the level of formal educational attainment is similar, there are important differences in the quality of the educational services delivered, to the detriment of the rural sector.

One reason for this disparity is that urban policy makers typically assume that cognitive skills are not needed for farming and that there is no new knowledge for agriculture. They view the business of farming generally as a rote or mechanical process, and one repeated mechanically year after year. For traditional agriculture, in which no technical change or new knowledge is being introduced, the typical perspective of the urban policy maker may not be inaccurate. However, once the process of technical change is under way, cognitive skills become very important, as do the specific inputs of new knowledge. The farmers need cognitive skills to decode the new knowledge used to modernize their production processes.

This raises important complementarity issues. For example, if no new production technology is being transferred to agriculture, the value of formal schooling for this sector will be quite low and the social rate of return to investments for this purpose alone will be low. If, on the other hand, the rate of technical change is high, the rate of return to investments in education for this purpose can be quite high. This raises an important issue of sequencing, which is as important to extension programs as it is to formal schooling. If there is no new knowledge available for the agricultural sector, and no capacity to produce new knowledge, there is little or no need for an extension system to diffuse knowledge. The same applies to the educational system.

An important caveat must be applied to both of these propositions, although it goes beyond the elements of science and technology policy. Both the extension services and the formal systems of schooling can contribute in other ways to improving the welfare of the rural population. Education, in particular, can contribute significantly to the preparation of the rural population for employment in the nonfarm sector of the economy. This can help the farm and rural population to gain remunerative employment, either on a part-time basis while still engaged in agricultural activities or by shifting completely to employment in the nonfarm sector. Such shifts in employment are the route to higher per capita incomes. To a lesser extent, the extension service can play a similar role.

Modern Input Policy

Let's now shift to still another element of science and technology policy. We noted earlier that much of the new knowledge of value to agriculture is imbedded in modern inputs. This is the case with improved varieties, which are imbedded in improved seeds. It is the case with commercial fertilizers and with pesticides. And it is the case with mechanical inputs.

An important dimension of science and technology policy for agriculture involves public policies that assure that these modern inputs are available to the producer in a timely manner and in an efficient way. When these inputs are first being introduced into the sector, there is a host of challenges in developing effective systems for distributing them and in providing entrepreneurs in that new sector sufficient instruction that they become knowledgeable suppliers of the inputs. The producers need to have available to them the right kind of inputs in a timely fashion. The distributors, for their part, need to know what inputs to obtain, where to obtain them, and in what form to make them available. Making that knowledge available to these new sectors is an important element of science and technology policy.

Agricultural Research in the Private or Public Sector

A major issue that arises once the importance of modern inputs is recognized is the choice between organizing agricultural research in the private sector or in the public sector. To the extent the new knowledge can be imbedded in modern inputs that can be sold in private markets, those producing that new knowledge will be reimbursed for their investments in producing it. Hence, the production of that kind of new knowledge can be left for the most part to the private sector.

When such "imbedding" is not feasible or the inputs—such as improved seeds—can be reproduced and passed from one farmer to another, underinvestment will result unless the public sector plays an important role. Thus the choice between organizing research in the private sector or in the public sector is another important element of science and technology policy.

Incentives for Modernization

The role that modern inputs play in the modernization of the agricultural sector raises another component of science and technology policy. Unless the use of the new inputs is profitable to the farmers, they will not adopt them. Thus, the incentives to adopt the new technology becomes an important issue. This opens the whole question of trade and exchange rate policy as factors affecting the domestic terms of trade—the ratio of agricultural prices relative to nonfarm prices. It also opens the issue of the price and availability of foreign exchange, which in turn shapes the availability and price of the new inputs for farmers.

Although these latter elements go beyond the core of science and technology policy, they are critical in determining the payoff from investing in the production of the new knowledge or technology. There is a high degree of complementarity between science and technology, on the one hand, and domestic price, trade, and exchange rate policy, on the other. One of the reasons for the sustained gross underinvestment in agricultural research and rural education in the past may be that policy makers recognized that by discriminating against their agricultural sector, the rate of return to investing in research, extension, and education would be quite low. With the policy stance of many governments currently becoming more favorable to agriculture, the importance of science and technology policy will come to the fore.

Developing a Cadre for Science and Technology Policy

A vital science and technology policy requires agricultural research and extension systems, as well as formal schools that help educate the rural population. These systems require a cadre of highly trained scientists. At the beginning of the modernization process, there typically is no such cadre, nor is there a capacity to train one.

A number of options can be pursued. One is to bring in expatriate scientists to staff such institutions or to staff key positions in them. Another is to annually send a promising group of people abroad to acquire the necessary skills. Still another is to develop graduate programs in the disciplines pertinent to the needs of the research, extension, and educational systems. Each of these options has its own set of challenges and problems to be resolved. However, a more detailed discussion goes beyond the present paper.

Issues in Developing a Sound Science and Technology Policy

The previous section provided an overview of the various elements of a science and technology policy and of the various kinds of decisions involved in developing a sound science and technology policy. As that discussion should have made apparent, the issues in developing such a policy are vast. In this section, however, no pretense is made about covering the issues completely. The goal is the more modest one of identifying some critical issues that need to be addressed in the current economic and social environment of sub-Saharan agriculture.

An Analytical Capacity for Decision Making

Most African countries have a significant infrastructure for delivering their science and technology policy. All too often, however, it is an infrastructure that reflects the historical experience of the country. In some countries the existing capability is a legacy of the colonial powers who dominated the continent at one time. The system may therefore not be attuned to the contemporary needs of the economy, especially as it seeks to re-integrate itself into the international economy.

More generally, policy makers are faced with a myriad of decisions as they try to strengthen and manage a modern and progressive science and technology system. They have little basis for knowing how many resources to allocate to science and technology. They have little basis for knowing how to allocate their scarce development resources among the various commodities produced in their country or what balance to seek between subsistence commodities and tradable commodities. They have little basis for knowing what skills are needed to have a system that focuses on the specific constraints that are limiting a more rapid rate of economic growth.

If efficient use is to be made of the scarce development resources available for science and technology and if the appropriate amount of resources is to be allocated to the sector, most countries in the region need an effective capacity to analyze the needs of the sector and to provide a sounder empirical basis for decision-making. These analytical entities need to be staffed with economists and other social scientists, as well as biological and natural scientists and engineers.

Having such scientists in a planning or analytical unit will not be a panacea, however. They will need to interact with policy makers and with scientists in the research and knowledge system more generally. It is only by such interaction that judgment can be pooled with the empirical evidence on what the best use of the resources will be. Making efficient use of the resources allocated to science and technology is critical if such resources are to contribute efficiently to economic growth and development.

Institutional Design

Institutional design issues are pervasive in a modern science and technology system and infrastructure. These institutional design issues are a critical factor in making efficient use of resources allocated to this sector.

The issues are legion. How many experiment stations are needed? Where should they be located (presumably one is needed for each ecological region)? What management and decision making system should be established? Highly centralized or highly decentralized? How will accountability be enforced?

At a different level, should basic research be integrated with applied research? What linkages are needed between the universities in the country and the agricultural and extension systems? Should the extension system be integrated with the research system? What is the most efficient system of extension given the prevailing social and economic conditions within the country?

At still another level, what kinds of rural education systems are needed under prevailing conditions? Are graduate programs in the agricultural sciences needed in the country? If so, how should the system be designed? Are formal exchanges needed with institutions of higher education in other countries? And with research institutions in other countries?

These organizational issues are an important key to the rate of economic growth and development. Institutional arrangements are an important form of human capital. These institutional arrangements are parallel in importance to production technology as a source of economic growth and development. The design work is thus important. It will be effective only if a proper analytical capacity is available to understand the needs of the system and to provide data for designing the system.

Financing the System

Almost every country in the world is struggling with the issue of how to finance its science and technology system. African countries have tended to have these activities organized in the public sector. But increasingly, the pressures are to pass these activities to the private sector.

Nevertheless, an important part of science and technology activities needs to continue in the public sector. The issue of allocating resources at a sufficient level that efficient rates of growth are induced is critical. The challenge is to sensitize policy makers to the high social rates of return to investments in science and technology.

An important principle for the guidance of resource allocation is that those who benefit from the system should help finance it. Thus, if farmers receive the bulk of the benefits, as in the case of tradable goods, they should be taxed in some way to garner the resources needed to support the system. This might be by means of export taxes, for example. Alternatively, a tax might be levied on output. If, on the other hand, consumers tend to receive the major share of the benefits, perhaps the more efficient way to support the system is through general tax revenue.

Designing an efficient and equitable system for capturing the resources to finance the science and technology system is essential for the sustainability of the system. Creativity and political will be vital elements in establishing a sound system.

Realizing Complementarities

Realizing complementarities is a critical element in making efficient use of the resources allocated to the sector. Earlier discussion suggested that there are a number of potential complementarities in the system. We consider only a few that help indicate the importance of the issue.

The failure to provide adequate operating resources is probably the most important factor leading to low productivity in the science and technology system, no matter whether one is considering domestic agricultural research systems, the extension system, or the public education system. Nothing is more frustrating than to see policy makers allocate resources to the employment of people, and then provide them no resources for operational purposes. Under these circumstances, the productivity of what in the individual instance may be substantial resources can well be close to zero.

There are similar issues among the major components of the science and technology system. Having an extension system without at the same time having an effective research capacity to create and evaluate new production technology will in the longer term lead to a weak extension service. The system will have nothing to distribute. The same applies to formal schooling. Without a steady flow of new technology, the payoff from investing in formal schooling may be quite limited in terms of the modernization of agriculture. In both this and the previous discussion, the issue of sequencing becomes critical in terms of realizing complementarities.

Still another potential source of complementarity is in the relationship between basic and applied research. There is a tendency to argue that the developing countries need to concentrate on applied research prior to launching into basic research. The evidence for such a division of labor is not at all clear. Under a rather wide range of circumstances, it may be necessary to sustain some basic research if the productivity of the applied research program is to be high.

Private Sector versus Public Sector

In many countries of sub-Saharan Africa, the role of the private sector may be one of the most critical issues facing policy makers. The legacy of prejudice against private companies, especially those representing large multinational firms, tends to be great. Moreover, there is a perception in many countries that the foreign company rapes the country when it takes germplasm out of the country for testing and for the creation of improved varieties through cross-breeding and biotechnology.

To be realistic, most countries of sub-Saharan Africa are not likely to have the resources to invest in science and technology at socially optimum levels into the foreseeable future. Therefore, they should seek to facilitate the entrance of private firms into the agricultural research, extension, and education establishment. This can be done by establishing appropriate protection for intellectual property rights. It can also be done by removing the barriers currently in place against the involvement of private firms, whether international or domestic.

International Transfer Issues

An important issue policy makers almost always face when they try to expand or strengthen their science and technology programs is the extent to which they should draw on international resources. Nationalism tends to play a strong role in these decisions, despite the good fortune the United States has experienced in attracting scientists from abroad.

One of the things that makes this difficult for the developing countries is the differential between national salaries and those that have to be paid to scientists from other countries. This disparity creates a significant equity problem, which policy makers in most countries are unwilling to accept.

There are a number of other dimensions to this issue, however. One is the transferability of the new technology. When the technology is transferable with relative ease, every effort should be made to take advantage of it. There is no reason to reinvent the wheel!

In the case of biological technology, especially plant improvements, this knowledge tends to be rather location specific. Improved varieties, for example, need to be developed in the ecological conditions under which they will be used. Nevertheless, there is much that can be done to take advantage of improved varieties developed in similar parts of the world. The international agricultural research centers of the CGIAR system collect and sustain significant collections of germplasm in the areas for which they are responsible. When new programs begin in specific areas, these collections are an important source of new plant material. Large trials can be installed for screening purposes, with the initial adaptation and breeding program proceeding from that base. Starting in this way, with as large a collection as possible, can make it possible for the program to move forward quickly.

There is a more general issue that in the longer term will be of great significance to the modernization of agriculture. The rapid internationalization of the global economy makes it increasingly easy to transfer knowledge from one part of the world to another. For basic research, therefore, the spillover effects are quite large. National governments find it increasingly difficult to retain the benefits of their investments in basic research. Under those conditions, it will be increasingly difficult to sustain investments in basic research at socially optimal levels. International cooperation will thus be increasingly important in the years ahead.

Developing the Capacity for Science and Technology

The rate of economic growth and development in most sub-Saharan African nations will be no greater than the capability they have in terms of numbers of scientists and effective teaching, research, and extension institutions. Viable institutions are critical to the future of these countries. But having qualified personnel to work and produce effectively is also critical.

For some developing countries, the capacity to deliver some of the human capital services has grown rapidly over the years. For others, the capacity is still at a rather low level. The need to strengthen and further develop that capacity is one that should continually be high on the agenda. The important issue is the need to recognize this as an important problem. Knowledge itself is a capital good that has many elements similar to that of physical capital. It depreciates in value over time, becomes obsolete, and generally needs to be refurbished. Thus continual reinvestments are needed.

The same applies to the stock of knowledge imbedded in the cognitive and other skills of researchers, teachers, and extension people. These skills also deteriorate, become obsolete, and need periodic replenishment. Continual reinvestment is needed to keep the skills of the professionals from deteriorating.

Some Concluding Comments

Science and technology policy is a critical part of modernizing agriculture. That modernization, which leads to broad-based increases in productivity, is the source of future increases in per capita income. The decisions required to have an effective science and technology policy are many and varied. Unfortunately, these issues receive all too little attention in contemporary policy discussions. The sense in which scarce development resources are involved, and the extent to which the production of knowledge and other forms of human capital are production activities to be organized, is neglected. Very little analysis goes into these decisions, and very little actual discussion of the issues takes place.

Investments in human capital are now the primary source of increases in output and in per capita income. The performance of most economies in the future will be largely determined by the decisions about science and technology in all its dimensions. Our capacity and willingness to address these issues needs to be greatly strengthened.

Workshop Participants

ABEBE Adera
Officer in Charge
Agriculture Division
U.N. Economic Commission for Africa
Addis Ababa, Ethiopia

ABERA Deressa
Center Manager
Melkasa Research Center
Institute of Agricultural Research
Melkasa, Ethiopia

ABERRA Debelo
National Sorghum Research Coordinator
Institute of Agricultural Research
Nazreth, Ethiopia

Mama ADAMOU-N'DIAYE
Ministre du Développement Rural
Cotonou, Bénin

ADANE Gudina
Head
Economic Sector
Oromyia Regional Council
Addis Ababa, Ethiopia

ADBECHO Washsso
Head
Agricultural Bureau Southern Region
Awasa, Ethiopia

Emmanuel ADDISON
Director
Ghana Crop Research Institute
Accra, Ghana

Kossi ADOMEFA
Directeur scientifique
Direction Nationale de la Recherche Agronomique
Lome, Togo

Georges AGBAHUNGBA
Directeur adjoint
Institut National des Recherches Agricoles
Cotonou, Bénin

Andrew AGLE
Director of Operations
Global 2000 Inc.
Atlanta, Georgia, USA

Kingsley Y. AMOAKO
Executive Secretary
U.N. Economic Commission for Africa
Addis Ababa, Ethiopia

Pierre ANTOINE
Director
Africa and Middle East Division
Winrock International Institute for Agricultural Development
Morrilton, Arkansas, USA

W. B. ASANTE
Vice Minister
Ministry of Food and Agriculture
Accra, Ghana

ASEFA Afeta
Senior Agronomist
Ministry of Water Resources
Addis Ababa, Ethiopia

ASEFA Woldegiorgis
Ethiopia Director
Farm Africa
Addis Ababa, Ethiopia

ASRAT Bulbula
Deputy Commissioner
Science & Technology Commission
Addis Ababa, Ethiopia

ASRES Workneh
Head
Department of Agriculture
Ministry of Economic Development & Cooperation
Addis Ababa, Ethiopia

Ekoué K. ASSIONGBON
Directeur Général du Développement Rural
Ministère du Développement Rural
Lome, Togo

Charles BAILEY
Representative
Ford Foundation
Nairobi, Kenya

Roger BANFIELD
General Manager
Cargill Hybrid Seeds
Arusha, Tanzania

Andrew BARNES
Programmes Department Head
Food for the Hungry International
Addis Ababa, Ethiopia

BATENO Kabeto
Head
Agricultural Development and Plant Protection Department
Ministry of Agriculture
Addis Ababa, Ethiopia

BEKELE Geleta
National Wheat Research Coordinator
Ministry of Agriculture
Addis Ababa, Ethiopia

BELAY Ejigu
Head
Agricultural Extension Services
Ministry of Agriculture
Addis Ababa, Ethiopia

Guy BELLONCLE
Professor of Rural Sociology
Université François Rabelais
Tours, France

BENTI Tolessa
National Maize Research Coordinator
Institute of Agricultural Research
Addis Ababa, Ethiopia

BERECHA Turi
Head of Extension Department
Oromyia Agriculture Development Bureau
Addis Ababa, Ethiopia

BERHANE Hailu
Head
Bureau of Agriculture,
Tigray Region
Mekele, Ethiopia

BERHANE Manna A.
Agriculture Operations Officer
World Bank
Addis Ababa, Ethiopia

BEWKETU Mokonnen
Project Officer
Christian Relief and Development Association
Addis Ababa, Ethiopia

BEYENE Kebede
Head
Department of Agriculture
Science & Technology Commission
Addis Ababa, Ethiopia

BIRHANU Tafete
Field Officer for Natural Resources
Sector Concern
Addis Ababa, Ethiopia

BOGALECH Alemu
Head
Women's Affair Department
Ministry of Agriculture
Addis Ababa, Ethiopia

Margaret BONNER
Counsellor for International
Development
Embassy of the United States
Addis Ababa, Ethiopia

Christian H. BONTE-FRIEDHEIM
Director General
International Service for National
Agricultural Research
The Hague, The Netherlands

Norman E. BORLAUG
President
Sasakawa Africa Association
Mexico D.F., Mexico

Carol BROWN
Team Leader
Monsanto Company
St. Louis, Missouri, USA

Baba Gallé CAMARA
Directeur Général
Service National de la Promotion
Rurale et de la Vulgarisation
Ministère de l'Agriculture, de
l'Elevage et des Forêts
Conakry, Guinea

Jimmy CARTER
Chairman
Global 2000
The Carter Center
Atlanta, Georgia, USA

Rosalynn CARTER
The Carter Center
Atlanta, Georgia, USA

CHEMERE Moges
General Manager
Development Bank of Ethiopia
Addis Ababa, Ethiopia

Steven C. COLLINS
Area Manager
Monsanto Company
Nairobi, Kenya

Ousmane COULIBALY
Consultant
Humid Forest Station
International Institute of Tropical
Agriculture
Yaounde, Cameroon

DIAGNE Gana
Representative
FAO
Bole Area
Addis Ababa, Ethiopia

Graeme DONOVAN
Principal Economist
Eastern Africa Department
Agriculture and Environment
Division
World Bank
Washington, D.C., USA

Richard DOWDEN
Journalist
The Economist
London, UK

Christopher DOWSWELL
Director for Program Coordination
Sasakawa Africa Association
Mexico City, Mexico

Jean DOYEN
Chief
Environmental and Sustainable
Development Division
Africa Technical Department
World Bank
Washington, D.C., USA

EFREM Bechere
Vice-President for Research and
Development
Alemaya Research Station
Alemaya University of Agriculture
Debre Zeit, Ethiopia

Joyce ENDELEY
Head
Department of Women's Studies
University of Buea
Buea, Cameroon

Robert EVENSON
Professor of Economics
Yale University
Economic Growth Center
New Haven, Connecticut, USA

FELEKE Belay
Head
Agriculture Bureau for Amhara
National Regional Government
Bahar-Dar, Ethiopia

FILLIPOSE W. Mariam
Economic Advisor to the President
The President's Office
Addis Ababa, Ethiopia

FIRKRU Abebe
Programme Director
Canadian Physicians for Aid and
Relief
Addis Ababa, Ethiopia

Vince FORLEY
Diplomat in residence
The Carter Center
Atlanta, Georgia, USA

Michael FOSTER
Country Director for Tanzania
Sasakawa-Global 2000
Arusha, Tanzania

Roland FOX
Senior Natural Resources Adviser
Overseas Development
Administration
Africa Division
London, UK

Antony FREETH
Filmmaker
London, UK

Jean F. FREYMOND
Director
Centre for Applied Studies in
International Negotiations
Geneva, Switzerland

FULASSA Sori
Agronomist
BASF
Addis Ababa, Ethiopia

Marcel GALIBA
Country Director for Benin & Togo
Sasakawa-Global 2000
Cotonou, Bénin

André GANMANVO
Directeur de l'Analyse de la
Prévision et de la Synthèse
Ministère du Développement Rural
Cotonou, Bénin

GETACHEW T/Medhin
General Manager
Ethiopian Seed Enterprise
Addis Ababa, Ethiopia

GETENET Gebeyehu
Deputy Head
Institute of Agricultural Research
Addis Ababa, Ethiopia

GHANEM Awad
Consultant
EEC-Shewa PADEP
Addis Ababa, Ethiopia

GHEBRE-MEDHIN Belay
Head
Planning and Programming Department
Ministry of Agriculture
Addis Ababa, Ethiopia

Mauro GHIROTTI
Animal Health and Production Officer
Embassy of the Republic of Italy
Addis Ababa, Ethiopia

Christina GLADWIN
Professor
Department of Food and Resource Economics
University of Florida
Gainesville, Florida, USA

Oumar GUEYE
Secrétaire Général
Ministère de l'Agriculture, de l'Elevage et des Forêts
Conakry, Guinea

GURMU Dabi
General Manager
Ethiopian Seed Agency
Addis Ababa, Ethiopia

Wayne HAAG
Country Director for Ghana
Sasakawa-Global 2000
Accra, Ghana

HAILU G. Mariam
Project Coordinator
Self Help Development
Addis Ababa, Ethiopia

Martin HANRATTY
Director,
Office of Agriculture
USAID Mission to Ethiopia
Addis Ababa, Ethiopia

John HARDMAN
Executive Director
The Carter Center
Atlanta, Georgia, USA

Robert HAVENER
Interim Director General
Centro Internacional de Agricultura Tropical
Cali, Colombia

Hans R. HERREN
Director
International Centre of Insect Physiology and Ecology
Nairobi, Kenya

L. Peter HERTELIUS
Agronomist
Swedish International Development Authority
Stockholm, Sweden

Irvin HICKS
Ambassador Extraordinary and Plenipotentiary
Embassy of the United States
Addis Ababa, Ethiopia

Michael HOLMAN
Africa Editor
The Financial Times
London, UK

Akira IRIYAMA
President
Sasakawa Peace Foundation
Tokyo, Japan

Yasunobu ISHII
International Affairs Department
The Nippon Foundation
Tokyo, Japan

Michio ITOH
Assistant Program Officer
Sasakawa Africa Association
Tokyo, Japan

Allen JONES
Director of Operations
U.N. World Food Program
Addis Ababa, Ethiopia

Monty JONES
Plant Breeder
West Africa Rice Development Association
Bouake, Côte d'Ivoire

Jean-Louis JUNOD
Former Director General,
André & Cie
Lausanne, Switzerland

Maurice KALUNDA
Deputy Director General
National Agricultural Research Organisation
Entebbe, Uganda

Jacob KAMPEN
Principal Agricultural Specialist
Africa Technical Department
World Bank
Washington, D.C., USA

Kaisa KARTTUNEN
Agricultural Advisor
Finnish International Development Agency
Ministry of Foreign Affairs
Helsinki, Finland

Gabriel KIENTAKA
Conseiller technique du Ministre
Ministère de l'Agriculture et des Ressources Animales
Ouagadougou, Burkina Faso

Minoru KIRIHARA
Third Secretary
Embassy of Japan
Addis Ababa, Ethiopia

Roger KIRKBY
Coordinator
Pan-Africa Bean Program
Centro International de Agricultura Tropical
Dar es Salaam, Tanzania

Aly KONTAO
Coordinateur National
Programme National de Vulgarisation Agricole
Ministère du Développement Rural et de l'Environnement
Bamako, Mali

Sylvester KORANG-AMOAKOH
Director
Agriculture Extension Services
Ministry of Food and Agriculture
Accra, Ghana

Akino KUAZUME
Resident Representative
Japan International Volunteer Center
Addis Ababa, Ethiopia

W. I. LINDLEY
Senior Officer
Agricultural Education and Extension Service
Human Resources, Institutions and Agrarian Reform Division
FAO
Rome, Italy

Christopher LIUNDI
Ambassador Extraordinary and Plenipotentiary
Embassy of the United Republic of Tanzania
Addis Ababa, Ethiopia

Christian LOUVET
Agronomist
ALM International
France

Björn LUNDGREN
Director
International Foundation for Science
Stockholm, Sweden

Clementina MACHUNGO
Director
National Directorate for Rural Development
Ministerio da Agricultura e Pesca
Maputo, Mozambique

Toshiro MADO
Program Officer
Agro-Processing Enterprise Development
Sasakawa Africa Association
Accra, Ghana

Luc MAENE
Secretary General
International Fertilizer Industry Association
Paris, France

Hidero MAKI
Senior Vice-President
Japan International Cooperation Agency
Tokyo, Japan

Hiroshi MATSUTANI
Resident Representative
Japan International Cooperation Agency
Addis Ababa, Ethiopia

Raphael MHAGAMA
Principal Secretary
Ministry of Agriculture, Livestock, Cooperatives and Development
Dar es Salaam, Tanzania

Masataka MINAGAWA
General Manager
Sasakawa Africa Association
Tokyo, Japan

Masaaki MIYAMOTO
Program Administrator
Sasakawa Peace Foundation
Tokyo, Japan

MOGES Abraha
Team Leader
Regional Affairs Section
The Prime Minister's Office
Addis Ababa, Ethiopia

Uzo MOKWUNYE
Director
International Fertilizer Development Center
Lome, Togo

Leen MOLENAAR
First Secretary
Embassy of the Netherlands
Addis Ababa, Ethiopia

Menwuyellet MOUSSIE
Technology Development and Transfer Advisor
Bureau of Africa, Office of Sustainable Development
U.S. Agency for International Development
Washington, D.C., USA

John B. MUBIRU
Director of Agricultural Extension
Ministry of Agriculture, Animal Industries and Forestry
Entebbe, Uganda

Russell MULELE
Director of Agriculture
Ministry of Agriculture, Food and Fisheries
Lusaka, Zambia

MULU Kestella
Advisor to the President
The President's Office
Addis Ababa, Ethiopia

Kalaluka MUNYINDA
Assistant Director
Ministry of Agriculture, Food and Fisheries
Lusaka, Zambia

Leighton J. MWALE
Assistant Director of Agriculture
Ministry of Agriculture, Food and Fisheries
Lusaka, Zambia

Wilfred MWANGI
Regional Economist
International Maize and Wheat Improvement Center
Addis Ababa, Ethiopia

Michael MZIRAY
Liaison Officer
Sasakawa-Global 2000
Dar es Salaam, Tanzania

Deola NAIBAKELAO
Africa Resident Representative
Sasakawa Africa Association
Accra, Ghana

Fidele NDAYISENGA
Research Associate
ACE Secretariat
Hubert H. Humphrey Institute of Public Affairs
Minneapolis, Minnesota, USA

Robin NEEDHAM
Director General
CARE Ethiopia
Addis Ababa, Ethiopia

Ole NIELSEN
Professor
Ontario Veterinary College
University of Guelph
Guelph, Ontario, Canada

Mutegi NJAU
Journalist
The East African
Nairobi, Kenya

Mohamood NOOR
Consultant
Special Program for African Agricultural Research
World Bank
Washington, D.C., USA

I. M. Nur
Head
Agriculture and Rural Development Division
Organization of African Unity
Addis Ababa, Ethiopia

Augustine O'Keeffe
Executive Director
Christian Relief and Development Association
Addis Ababa, Ethiopia

A. V. Obeng
Senior Liaison Officer
FAO
Addis Ababa, Ethiopia

Victoria Odoi
Journalist
Graphic Newspaper Corp.
Accra, Ghana

Vagn Oestergaard
Director of Research
Danish Institute of Animal Research
Research Centre Foulum
Tjele, Denmark

Gunnar Oeygard
Advisor to the Vice-Chancellor
Norwegian Centre for International Agricultural Development
Agricultural University of Norway
Aas, Norway

Antony Okello
Commissioner for Land Protection
Ministry of Agriculture, Animal Industries and Forestry
Entebbe, Uganda

Patrick Orr
Raitt Orr and Associates
London, UK

Thomas A. Osborn
Seed Systems Specialist
Development Strategies for Fragile Lands
Washington D.C., USA

José Pacheco
Vice-Minister of Agriculture and Fisheries
Ministerio da Agricultura e Pesca
Maputo, Mozambique

Rachael Percy
Consultant
Ministry of Agriculture
Addis Ababa, Ethiopia

Petros Godana
Head
Agriculture Bureau of Southern Region
Awassa, Ethiopia

David Piraino
Director General
Catholic Relief Services
Addis Ababa, Ethiopia

Donald Plucknett
President
Agricultural Research and Development International
Annandale, Virginia, USA

Marco A. Quiñones
Country Director
Sasakawa-Global 2000
Addis Ababa, Ethiopia

Michael Rewald
Assistant Country Director
CARE Ethiopia
Addis Ababa, Ethiopia

Johannes Roseboom
Researcher
International Service for National Agricultural Research
The Hague, The Netherlands

Amit Roy
President
International Fertilizer Development Center
Muscle Shoals, Alabama, USA

Joan Kakima Rwabyomere
Minister of State
Ministry of Agriculture, Animal Industries and Forestry
Entebbe, Uganda

James G. Ryan
Director General
International Crop Research Institute for the Semi-Arid Tropics
Patancheru, Andra Pradesh, India

Iyatan Sabi
Directeur de la Vulgarisation Agricole
Ministère du Développement Rural
Lome, Togo

Akira Sakashita
Manager
Public Affairs Department
The Nippon Foundation
Tokyo, Japan
Ohenese Apau SAKYI
Agronomist
Sasakawa-Global 2000
Accra, Ghana

Pedro Sanchez
Director General
International Centre for Research in Agroforestry
Nairobi, Kenya

Yohei Sasakawa
President
The Nippon Foundation
Tokyo, Japan

Toshimitsu Sawai
Journalist
Kyodo News Agency
Nairobi, Kenya

J. F. Scheuring
Manager
International Maize Hybrid Breeding
Ciba Seeds
Basel, Switzerland

Ebbe Schioeler
Adviser-Head of Research Section
Danish International Development Agency
Copenhagen , Denmark

G. Edward Schuh
Dean
Hubert H. Humphrey Institute of Public Affairs
University of Minnesota
Minneapolis, Minnesota, USA

Meera Seethi
Resident Representative
International Organization for Migrations
Addis Ababa, Ethiopia

Victoria Sekitoleko
Sub-Regional Representative for Southern and Eastern Africa
FAO
Harare, Zimbabwe

Seyfu Ketema
Director General
Biodiversity Institute
Addis Ababa, Ethiopia

SEYOUM Halake
Oromyia Agriculture Development Bureau
Addis Ababa, Ethiopia

Francis SHAO
Commissioner for Research and Training
Ministry of Agriculture, Livestock Cooperatives and Development
Dar es Salaam, Tanzania

SHUMET Admas
Director General
Ethiopian Relief Organization
Addis Ababa, Ethiopia

SIMEON Assefa
Rural Credit Officer
Commercial Bank of Ethiopia
Addis Ababa, Ethiopia

SINTAYEHU Gebre Mariam
Acting Vice-Minister of Agriculture
Ministry of Agriculture
Addis Ababa, Ethiopia

Daag SKOOG
First Secretary
Development Cooperation Office
Embassy of Sweden
Addis Ababa, Ethiopia

Michael E. SMALLEY
Director
Training and Information
International Livestock Research Institute
Addis Ababa, Ethiopia

Hamadoun SOW
Chef de Cabinet
Ministère du Développement Rural et de l'Environnement
Bamako, Mali

Roger STEELE
Program Officer
Winrock International Institute for Agricultural Development
Morrilton, Arkansas, USA

TADELECH H. Micael
Minister
The Prime Minister's Office
Addis Ababa, Ethiopia

TADESSE Kebede
Commissioner
Science & Technology Commission
Addis Ababa, Ethiopia

Koichi TAKAGI
Director
Department of International Affairs
The Nippon Foundation
Tokyo, Japan

TAKELE Gebre
SG 2000 National Coordinator
Ministry of Agriculture
Addis Ababa, Ethiopia

TAMIRU Habte
Head
Rural Technology Promotion and Land Use Planning Department
Ministry of Agriculture
Addis Ababa, Ethiopia

TAMRAT Mekonen
Rehabilitation Coordinator
Save the Children Fund UK
Addis Ababa, Ethiopia

TAREKE Berhe
Senior Agronomist
Sasakawa-Global 2000
Accra, Ghana

Bezuneh TAYE
International Coordinator and Director of Research
Semi-Arid Food Grain Research and Development
Organization of African Unity
Ouagadougou, Burkina Faso

Michael TEKESTEBREHAN
Head
Economic Affairs
The Prime Minister's Office
Addis Ababa, Ethiopia

TEKETEL Forssido
Acting Minister of Agriculture
Ministry of Agriculture
Addis Ababa, Ethiopia

TEKLEWOINI Assefa
Executive Director
REST
Addis Ababa, Ethiopia

TESFAYE Besha
Lecturer
Alemaya Research Station
Alemaya University of Agriculture
Debre Zeit, Ethiopia

Roseta TETEBO
Director
Women in Agricultural Development
Ministry of Food and Agriculture
Accra, Ghana

Robert THOMPSON
President
Winrock International Institute for Agricultural Development
Morrilton, Arkansas, USA

TIBEBU Zewdie
Economic Officer
Embassy of Japan
Addis Ababa, Ethiopia

Moctar TOURÉ
Executive Secretary
Special Program for African Agricultural Research
World Bank
Washington, D.C., USA

T. TSUCHIYA
Deputy Managing Director
Agriculture, Forestry and Fisheries Development Study Department
Japan International Cooperation Agency
Tokyo, Japan

Jose VALENCIA
Country Director for Nigeria
Sasakawa-Global 2000
Kano, Nigeria

Jack VAN HOLST PELLEKAAN
Poverty Advisor
Africa Technical Department
World Bank
Washington, D.C., USA

Ralph VON KAUFMANN
Director of External Relations
International Livestock Research Institute
Addis Ababa, Ethiopia

Jungahe WAINAINA
Regional Manager for Eastern Africa
FMC International
Nairobi, Kenya

Tairou WAKILI
Chef du Service d'Appui à la Vulgarisation Agricole
Ministère du Développement Rural
Cotonou, Bénin

Christopher D. WALLER
Zeneca Agrochemicals Ltd.
Haslemere, Surrey, UK

WERQU Mekasha
Country Director
Volunteers in Overseas Cooperative Assistance
Addis Ababa, Ethiopia

James B. A. WHYTE
Earrnet Coordinator
East and Southern Africa Regional Centre
International Institute of Tropical Agriculture
Kampala, Uganda

WUBE Adera
Head
Extension and Cooperative Promotion Department
Ministry of Agriculture
Addis Ababa, Ethiopia

Jean-Christophe YAMEOGO
Secrétaire Général
Ministère de l'Agriculture et des Ressources Animales
Ouagadougou, Burkina Faso

Hamada YASUHIRO
Ambassador Extraordinary and Plenipotentiary
Embassy of Japan
Addis Ababa, Ethiopia

YIMENU Jemberie
Agronomist
Chemtex Private Limited Co.
Addis Ababa, Ethiopia

YOSEPH Hilawe
Director General
Amhara Development Association
Bahir Dar, Ethiopia

YOSEPH Imana
Ministry Capacity Building Director
World Vision International Ethiopia
Addis Ababa, Ethiopia

Carlos ZANDAMELA
Director
Instituto Nacional de Investigaçao Agronomica
Maputo, Mozambique

Ibrahim A. ZEIDY
Director
Economic Research Department
National Bank of Ethiopia
Addis Ababa, Ethiopia

ZEMENE Simie
Head
National Agricultural Research Planning Division
Ministry of Economic Development and Cooperation
Addis Ababa, Ethiopia