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African Agricultural Research Capabilities

Committee on African Agricultural Research Capabilities
BOARD ON AGRICULTURE AND RENEWABLE RESOURCES
of the
COMMISSION ON NATURAL RESOURCES
and the
BOARD ON SCIENCE AND TECHNOLOGY FOR INTERNATIONAL DEVELOPMENT
of the
COMMISSION ON INTERNATIONAL RELATIONS
National Research Council

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Preface

The wave of independence that swept over Africa during the 1950's and 1960's brought to light new and urgent problems toward which African agricultural research should be directed. In one way, continental agricultural research was less complicated before independence. Then, governments of the three principal colonial powers could organize research within their groups of colonies without regard to African political boundaries; thus, they could more easily design attacks on problems affecting broad ecological zones, such as the savanna or the tropical rain forest. Important elements of this intercolonial superstructure have now dissolved, and each new nation must now struggle individually to organize and carry out its own agricultural research and find new ways of working in cooperation with other African nations to realize its research goals.

This situation offers an obvious opportunity for international research organizations. They can, for example, take responsibility for work that extends beyond the scope of a single African nation and help ensure that various intracontinental efforts reinforce, rather than duplicate or compete with, one another. However, the situation also creates a problem for donor agencies in deciding how to allocate resources for African agricultural research among the various independent nations. Hence, the need to establish priorities.

An early effort to assess needs in the context of independence began in 1959. In that year, the United States International Cooperation Administrator, the predecessor of the United States Agency for International Development (USAID), asked the National Academy of Sciences (NAS) to advise on the scientific, technological and educational needs of the newly formed African nations. Rural development and agricultural research were important components of the study that resulted (NAS, 1959). A steering committee created for the study grew into NAS's Africa Science Board.

During the 1960's the education of African scientists moved apace. Africans themselves for the first time were able to participate in agricultural research on an international level in establishing needs and priorities. In earlier research efforts, few Africans had been trained or employed even as technicians. In 1968 the Africa Science Board, with the cooperation of African governments and the Food and Agriculture Organization (FAO) of the United Nations and the support of USAID, organized an international conference on agricultural research priorities at Abidjan, Ivory Coast (NAS, 1968). The conference was attended by about 200 persons from 32 countries of sub-Saharan Africa, North America, Europe and Asia, as well as from key international organizations. Though the conference did not rigorously order priorities, its 11 commissions identified critical problems requiring intensified research and political initiative.

Delegates to the Abidjan conference saw a need for a permanent forum of agricultural scientists transcending institutional and governmental affiliation that could objectively consider research priorities. To fill this need they formed the Association for the Advancement of Agricultural Sciences in Africa (AAASA), which held a general assembly in 1971 in Addis Ababa, Ethiopia.

Just prior to that, in 1970, in response to USAID's request for the present study the Office of the Foreign Secretary and the Agricultural Board of the National Academy of Sciences/National Research Council appointed a steering committee for the present study. The steering committee helped select the Committee on African Agricultural Research Capabilities, which prepared the present report. The Committee was composed of 17 members from Africa, Europe and North America (see list on p. x). They represented a wide range of organizations and of disciplines in the agricultural sciences and brought to the group a broad fund of experience across Africa. In the course of its work, the Committee drew heavily on the knowledge and opinions of the community of African scientists and of many other colleagues around the world as well as on its own expertise.

At the outset, the steering committee established goals for this study:

- To review and rearrange the agricultural research and educational priorities for Africa, or, if necessary, establish altogether new priorities to enable agricultural science to make its maximum contribution to the development goals for Africa. The development goals are identified in recent national and international studies, such as the FAO *Provisional Indicative World Plan for Agricultural Development* (FAO, 1969a) and the report of the 1968 Abidjan conference (NAS, 1968).
- To determine the appropriate role of non-African agencies in the coordination of agricultural research and education within Africa and, where advisable, to determine the specific subject areas and physical locations for these non-African agencies. No coordinating efforts are to be planned, of course, which might encroach on the developing contributions of African institutions and the desires of the African peoples.
- To suggest appropriate channels of communication and cooperation among nations and institutions–inside and outside Africa–in agricultural research and education.
- To outline the means by which research and education can be applied most effectively to African agricultural development.
- To make a broad assessment of the scientific manpower needs of the research systems and institutions recommended by the Committee, to review African scientific personnel now available for this purpose, to identify scientific manpower gaps and needs, and to establish manpower priorities.

In April 1971 the Committee outlined the topics it believed the study should cover. In September 1971 it refined that outline, and in the same month it convened in Addis Ababa specifically to allow its members to converse with the 129 agricultural scientists, representing 20 African countries and 8 European and North American countries, attending the AAASA conference. By December the Committee had developed a preliminary draft of the report. In March 1972 it held its fourth session at The Rockefeller Foundation Conference Center at Bellagio, Italy; its fifth and final meeting took place in April 1973 in Dakar, Senegal.

Several surveys and studies conducted by other agencies in 1970 and 1971 relate closely to this project. Those that have been particularly useful are listed below:

- The series of 15 seminars sponsored jointly (from January 1970 through July 1971) by the Ford Foundation, the Institut de Recherches

Agronomiques Tropicales et des Cultures Vivrières (IRAT) and the International Institute of Tropical Agriculture (IITA). Among other topics, these seminars covered quantitative and qualitative improvement of food crop production, improvement of traditional African agricultural systems, and mechanization in African agriculture. (The seminars will be published by IITA under the title *Food Crops of the Lowland Tropics.*)

- The IITA research program for the humid tropics of Africa and the scrutiny of it by distinguished review panels.
- The FAO Conference on the establishment of Cooperative Agricultural Research Programs between Countries with Similar Ecological Conditions–Guinean Zone, Africa (FAO, 1971b). This conference was held in Ibadan, Nigeria, in August 1971 in cooperation with the Ford Foundation and IITA. A similar conference on the Sudanian zone was held in 1968 (FAO, 1969b).
- The papers of the 1971 meeting, already mentioned, of the AAASA.
- The reports of three NAS-sponsored projects–the Committee on Tropical Soils, the Ghana Workshop, and the Congo Workshop. (NAS, 1972, 1971b, 1971a). In its report *Soils of the Humid Tropics* (NAS, 1972), the Committee on Tropical Soils identified knowledge gaps and established research priorities for the topic of African soil productivity. The Ghana Workshop, held in Accra in January 1971, looked at agricultural research as it affects agricultural policy in Ghana and the means by which the results of research can have an impact on farmers' practices. The Congo Workshop, held in Kinshasa in June 1971, led to an agreement for organizing a team of economists to assess agricultural research opportunities as they can be brought to bear on economic development under the government's Five Year Plan. The workshop also recommended a nationwide study of needs and deficits of food and key nutrients such as proteins and of ways to overcome them.

Many agencies have organized *ad hoc* task forces to undertake in-depth studies of aspects of African agricultural development, notably livestock development, control of livestock development, control of livestock diseases, and improvement of upland crops such as sorghum, the millets and grain legumes. These studies stem from recognition by the Consultative Group for International Agricultural Research (CGIAR)–a consortium of national and international aid and development agencies and philanthropic organizations–of the need to intensify agricultural research on a worldwide basis.

Other publications which have provided useful insights and helpful guidelines are listed at the close of this report.

The NAS Committee on African Agricultural Research Capabilities is fully aware of the magnitude of the task it faced and of its shortcomings in trying to perform it. The Committee hopes, however, that it has satisfied to some degree the terms of reference assigned to it and that the report will be of basic interest to agriculturalists, planners and policymakers in aid-giving and aid-receiving nations, and in the international agencies, who are concerned with the development of African agriculture.

In addition, the Committee hopes that the report will stimulate the growth of an integrated agricultural research system in Africa. Such a system will maximize linkages and cooperation among international and national research efforts and will produce a more rational distribution of research functions.

Finally, the Committee hopes that this report will suggest opportunities to USAID and to similar agencies of other countries for applying their resources in support of research for African agricultural development.

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Dr. Joyce C. Torio, Staff Officer, Board on Agricultural and Renewable Resources, to whom her husband, Mr. Dan Torio, gave valuable assistance, worked tirelessly in all aspects of the administrative and scientific development of the study; the Committee owes her an especially deep debt of gratitude. Dr. M. G. C. McDonald Dow, Deputy Director, Board on Science and Technology for International Development, assisted professionally and expedited the completion of this report.

Contents

Introduction

This study essays an answer to an apparently simple question–In the diverse and changing circumstances of tropical Africa today, how can agricultural science and specifically agricultural research contribute most effectively to the progress of the African nations and peoples?

Africa has long had a network of research stations (see MAP, *inside back cover*), producing results equal to those achieved in many other parts of the world. African investigations led to ridding some areas of the continent of the deadly tsetse flies. In addition, research in Africa on the biology of locusts made possible their containment in limited areas of East Africa. Local agricultural research provided a high-yield cotton with long staple fibers, which competed successfully for markets with other cotton-producing countries. African studies of pests and diseases affecting the cocoa industry yielded enormous benefits. Other local research efforts dealt effectively with the problems of African producers of oil palm, groundnuts and other important products.

Much of this research, however, was directed toward commercial agriculture and, therefore, chiefly benefited plantation owners or foreign companies. Little was done, for example, to improve the yield of food crops without international commercial significance or to remedy the problems of African small farmers and herdsmen. There were exceptions, of course, to this general rule, such as the very effective work with the cassava, a staple in the diet of millions of Africans. African research produced varieties that were resistant to the virus mosaic disease. Yet, there is room for much more research of this kind.

To be sure, investigations along well-established technical lines can still be fruitful. Studies of the use of sterile male flies for example, may clear large new areas of tsetse. Work on the hormones that control the length of locusts' wings, a factor which governs the transition of this pest to the migratory phase, will further strengthen locust control. If Africa is to maintain its competitive position and satisfy increasing needs of the textile industry, cotton research must be continued; likewise, vigilance is necessary against new outbreaks of cocoa disease and cocoa pests.

On the other hand, Africa and African agriculture are changing fast, and African agricultural research must rearrange its priorities to accommodate the new needs of the African people. During the past 20 years, almost all of Africa–from the Orange and Limpopo rivers to the Sahara–has become politically independent. Territories formerly controlled by three foreign powers now constitute 30 new African states, with different environments, resources, peoples, languages, historical traditions and international associations.

The economies of the African states are changing also, and the size of agriculture's contribution to them is growing rapidly. More and more farming and pastoral communities are raising crops and stock for sale. Some small farmers have even become modern producers, specializing in a single "cash crop," and have given up subsistence farming altogether. The roads, railways, harbors, water and power supplies, and input and output delivery systems necessary to support these changes are constantly being extended.

Populations are increasing rapidly as improvements in health and other conditions enable more babies to survive and their parents to live longer. Though the towns continue to grow in size, the absolute number of rural people seems likely to increase for most tropical African nations for many years to come.

The social consequences of this growth are far-reaching. Africa, like other continents, is now experiencing the easier travel, greater educational opportunities, greater contact with markets and population shifts from rural to urban areas that have been altering life for many years. A new cadre of leaders, drawn from many different backgrounds and traditions, provides professional and administration services. Simultaneously, a new urban working class–largely underemployed and partly unemployed–presents another facet of the shape of things to come, as the flow of goods between agricultural and nonagricultural sectors swells the manufacturing and service sectors of African national and regional economies.

For the immediate future, however, most tropical African economies will continue to rely on agriculture. The new role of agriculture will require an expanding and changing base of knowledge, including knowledge of the environment—the organisms that live in it (useful and otherwise), the systems in and by which these organisms can be managed—and of the economic and social facts of life in the rapidly changing African societies. In other words, more, different and, if possible, better agricultural research will be essential.

I

Key Problems Facing African Agriculture in the 1970's and Projections to the Year 2000

Three key problems of African agriculture stand out as needing immediate attention: (1) how to increase food output and improve nutrition; (2) how to help alleviate the uneven economic development that occurs between farm and nonfarm sectors of the economies of African nations; and (3) how to formulate a policy that will ensure that agricultural research works in the best interests not only of the individual African nation, but also of the region in which that nation is situated and of the continent of Africa as a whole. The solutions to these key problems are interrelated.

INCREASING FOOD OUTPUT AND IMPROVING NUTRITION

Substantial shortages of food and inadequate nutrition affect millions of people in Africa. Those people living in marginally productive regions of Africa often experience local food shortages and sometimes suffer from hunger gaps—witness the persistent drought which, during the past several years, has been plaguing the tier of countries bordering the Sahara Desert in West Africa and which culminated in disaster conditions in 1973–1974. Throughout Africa, people of certain social groups and geographical regions—the humid tropics, especially—need more protein. Among those most vulnerable to this type of malnutrition are pregnant and nursing mothers, children and the aged.

Agricultural science must bear the overwhelming responsibility for overcoming these inadequacies. Inevitably, population growth increases the burden. Some areas, such as the savanna of Africa where soils are poor and rainfall is light, have trouble supporting a relatively small population. Others, such as eastern Nigeria and parts of the East African highlands, are as crowded as some parts of Asia. Not only is the absolute number of rural people likely to increase substantially in the foreseeable future, but the growth rate itself is at 2.2–2.6 percent per year for most African countries.

One research goal, then, is to increase agricultural production, whether for subsistence living, for the market economy, or both. Clearly agricultural production must increase much more rapidly than the population if the present standard of living is to be maintained. The discovery of new marketable agricultural commodities is a subsidiary effort in research to increase food output as the sale of these would help enhance the purchasing power of rural people and, theoretically, enable them to be better fed. The second absolutely essential goal is better nutrition. Standards must be set for what constitutes a balanced African diet, and, in many cases, the nutritional value of the food that is consumed must be improved to meet the standards.

To some extent, the protein deficit in Africa might be reduced by breeding more and better protein into cereal varieties (see Chapter IV), but grain legumes (see Chapter V), because they start with a better protein base, would seem to offer an even better opportunity for increasing the protein intake of people living in the tropics. Cassava, sweet potatoes and yams—foods favored over much of the humid tropics where cereals grow poorly—present good research possibilities for obtaining greater yields and higher nutritional value (see Chapter VI). As the urban population increases in size and affluence, its demand for standard fruits and vegetables (see Chapter VII) will undoubtedly rise; research directed toward growing them in the neighborhood of the cities will then be necessary. Rural populations, on the other hand, would benefit from research on the less well-known local vegetables and fruits that are important to their diet.

One way of providing better quality proteins, of course, is to make animal products more widely available at less cost. Technological improvements in livestock and forage production, disease control, and transportation and processing of these products are necessary. Reduced feed costs from improvements in cereal production should also help expand supplies of livestock and poultry products.

Agricultural science's responsibility for improving the nutrition of the African people is a shared responsibility. Other disciplines, such as public health and education, and factors, such as the levels and distribution of incomes, bear significantly on the nutrition problem.

For example, to pursue certain agricultural goals may endanger the health of farmers and others. To grow paddy rice or to expand the area of paddy rice culture in parts of West Africa where malaria is widespread may create conditions that lead to greater incidence of this disease among the people in that area. To increase the area planted in upland rice, sorghums or the millets in the upper reaches of the Volta River basin may expose greater numbers of people to the black flies along the river banks that transmit river blindness. Impounding water for irrigating lands where schistosomiasis, borne by a water snail, is endemic can increase the chances that field-workers will contract that disease. To associate cattle with game animals in the same rangelands may mean the cattle will suffer from trypanosomiasis, known also as *nagana*, where tsetse flies prevail and transmit the disease that debilitates and kills the cattle. Large increases in agricultural production are possible in regions where health hazards exist, but only if proper health measures are taken to protect human beings and their livestock from disease.

Nutritional research must be complemented with education if available nutrients are to be put to efficient use. Traditional ways of preparing food may waste significant amounts of its protein content and require excessive amounts of time and energy that could be better used for other purposes. Social attitudes may prevent other valuable foods from being used. Promoting better ways of feeding pregnant women, children and the ill is a function of education. A complementary approach for the agricultural scientists, in this case food technologists, would be to discover new ways to prepare food that would meet the aesthetic demands of the people as well as raise the nutritional standards of the final product.

Levels and distribution of income profoundly affect the kinds of food that people will eat and grow. People with large incomes prefer rice and other cereals. As incomes increase, demand for these grains will grow, intensifying the need for research on them. Rising incomes will also enable Africans to buy more meat, milk and eggs, thus reinforcing the need for research to increase low-cost output.

In summary, improvements in health and education and enhancement of income must accompany agricultural development if people are to have adequate food and good nutrition.

UNEVEN DEVELOPMENT

Economic development in tropical Africa has led to unbalanced growth, resulting in an increasingly skewed distribution of income, migration to select (primarily urban) areas, and growing urban underemployment and unemployment. But there are positive aspects to this development. For example, a precondition of general progress in Africa is the interaction that emerges from the polarity of economic life between farm and nonfarm sectors. Correctly managed, this interaction appears to offer a practicable general way forward from the poverty and stagnation of traditional rural life. Within this course to progress, agricultural development—necessarily based on productive technology—must play a leading part.

Migration from country to town takes place everywhere, but its occurrence in Africa is among the highest in the world. The cities are overburdened by this sudden influx of people, many of whom are poor. More research is necessary before the social and economic reasons for this migration and its consequences can be understood. In general, however, migration is encouraged by "pull" and "push" factors. "Pull" factors in the cities include high money wages and increased social amenities relative to those available in the rural areas. "Push" factors in the countryside include the lack of medical services, education facilities and employment opportunities. The economic security of the African small farmer is further threatened by low income. Part of the reason for these low incomes is the low productivity of farm families. Seasonal unemployment of farmers is a serious problem. During the long dry season in the Sudanian and Saharan zones farmers and their families have virtually nothing to do unless they have livestock or can work in small industries. More research applied toward generating employment and lifting the productivity of low income groups in rural areas is needed to raise incomes and slow migration.

However, even under the best of circumstances, migration will continue, and increasing numbers of people will enter the urban labor market. A high proportion of these will have to be employed in those industrial and service sectors that are linked to agricultural production. Research that leads to a general rise in agricultural productivity will help increase employment. At the same time, the research on food crops proposed in this report should improve the welfare of those who remain in agriculture—especially the lower income groups—and so contribute to reducing the maldistribution of income and minimize the uneven development of urban and rural areas.

AGRICULTURAL SCIENCE POLICY

A sound agricultural policy, correctly articulated with the national development policy as a whole, is essential if the national goals are to increase food output, improve nutrition and cope with the interaction of economic life between farm and nonfarm sectors. A key component of this policy is obviously scientific, for it will be impossible to respond to national growth needs without the wise use of science in developing the biological, human, social and economic resources of the African nations. Agricultural science policy must ensure that (1) necessary knowledge, new and old, is available; (2) a sufficient number of men and women are properly trained to serve a modern, science-oriented agricultural industry in the laboratories, the classrooms, extension divisions and fields; (3) agricultural research and education programs are properly designed and implemented; and (4) appropriate institutions for agricultural research, extension and development are established and operate effectively.

The attitudes of local government toward research are crucial in the development of such a policy. Strengthening existing African research institutions; creating new ones where necessary and advisable; supporting faculties of agriculture in the training and education of manpower for research; and developing appropriate means of communication among researchers, administrators and farmers constitute some of the most important facets of such a policy. The recommendations of this report will center on these issues.

II

Agricultural Systems

Isolated technical or economic advances alone do not solve major problems. Nowhere is this lesson better shown than in Africa's experience with the Green Revolution. Achieving a significant advance here required not only the specific development of improved seed but changes in the overall network of systems that (1) produce farm products; (2) supply the modern input and factors of production that carry the new technologies; (3) market, transport and retail farm products; (4) regulate, control, tax and/or subsidize farming and agribusiness activities; and (5) shape and control the developing patterns of resource ownership and hence of income distribution. A shortcoming in any of these areas lessens the effectiveness of work in any or all of the other areas. Reduced to its simplest terms this is the concept of a *package of practices.* Good seeds with fertilizer, good agronomic practices with appropriate technology, the application of insecticides to protect improved varieties in concert constitute the package of practices that gave the quantum jump in productivity characterized as the Green Revolution.

Our specific examination of research needs and capabilities, therefore, begins with a discussion of the systems that make up or embrace agriculture.

CHEMICAL, PHYSICAL AND BIOLOGICAL SYSTEMS

At the most basic level, agricultural systems are assemblages of plants, wild or domesticated. Human beings utilize these plants directly, or secondarily, through animals. The receipt, loss and balance of radiation, water, carbon dioxide and plant nutrients regulate the output of such assemblages. In the semiarid tropics, and even in many temperate areas, crops have to be managed to concentrate the use of available water and other environmental components so that single crops can be grown and marketed within the most favorable short season of two to four months. In most temperate regions growth is restricted by cold; in the tropics it is restricted by drought. Growth in the tropics is possible without irrigation only when rainfall exceeds evaporation–the opposite of the rainfall and evaporation regime in the temperate zones.

Study of plant assemblages as chemical, physical and biological systems provides a base for measuring how closely actual production approaches its potential. This comparison indicates what environmental or biological factors may be limiting production and so points to more effective ways for managing the environment. Even at these basic levels, the wants and needs of man are important. The value to human beings of what goes into the system and what emerges from it are crucial in determining the value of different possible systems.

SINGLE CROP AND LIVESTOCK SYSTEMS

In the single crop or livestock system the crop, the crop association or animal species constitutes an enterprise. If a farmer raised cotton, cattle and a variety of subsistence crops, for instance, the cotton and each of the other crops and types of animals would be considered a separate enterprise within this system. The results of studies of potential productivity and yield at the biological level determine the level of conventional agronomic research. Here, the object of systems studies is to build a matrix of information from which the optimum mixes of inputs for a single enterprise (crop) can be computed for all mixes of prices likely to be experienced by the unit of the next higher system, the farm.

Much excellent agronomic work has been done in tropical Africa, particularly on export crops. Too much of it, particularly on food crops, has been limited by an assumption that only the range of inputs used in traditional subsistence systems can be considered.

To make such research useful for systems studies, four features are necessary:

1. The effects of variable technical factors and inputs–fertilizers, manures, protection chemicals, water, time (as in sowing date experiments) and space (as in studies of density, arrangement or stocking in-

tensity)—must be studied at enough levels to define the relations of changes in factors and inputs to changes in output.

2. Since factors do not operate alone, all but the initial experiments in a program should probably be designed so that interactions between factors (variety and nutrition, for example) can be detected and measured.

3. The capital and recurrent costs, as well as the predictable returns for individual technical inputs, must be reliably known.

4. The overall effect of variations due to technical factors and power* requirements, including the amount of human labor employed, must be measured, or at least reliably estimated.

MANAGEMENT UNIT (FARM) SYSTEMS

At the management unit level, a farm family assembles individual enterprises into systems. The family may not be able to allocate to each crop (or enterprise) all the resources necessary to achieve the greatest possible yield. The family must therefore use its resources as best it can to maximize the return from the farm system as a whole.

Factors that may influence management unit level decisions include cost constraints (such as costs of labor and other sources of power, base costs, etc.) physical constraints (such as seasonal variations in the labor supply, variations in the health and nutrition of the laborers, etc.) and cultural restraints (attitudes toward the land, attitudes about the way labor should be divided between men and women, for example, or between residents and migrants or between different sorts of people in the society). Studies of these factors can identify the points where extra power or better equipment would most effectively increase the total volume of productive work for the year and thus the number of people the system can maintain.

The agronomist's first contribution toward improving farm systems is made through definition of the requirements and the predictable responses of individual crops. These can then be studied in combination through the multifactorial rotation experiment†, including livestock as well as crops where appropriate. Such experiments are large and costly and usually must continue for several years. They must, therefore, be

**Power*, in the sense used here, can be supplied by the labor of men and women, by draft animals or by machines.

†A *multifactorial rotation experiment* is one that includes a number of different types of treatments—different types of crop rotation sequence, dates of planting, fertilizer, etc.—to identify which treatment is most appropriate for the particular farming conditions.

flexible in design so as to be easily altered as early ideas become less relevant and new possibilities emerge. Experiments with two consecutive crops can help to identify technically undersirable sequences. Rotation experiments should include the same four general features as the enterprise studies–factors at several levels, factorial design, measures of cost and measures of power demand.

Simulation studies may prove helpful in overcoming the constraints of large multifactorial experiments and in accelerating the collection of information on which to base predictions. Simulation of different moisture regimes and probability analysis of climatic patterns possible under each regime is an example. Studies simulating the operation of whole farms, based on single crop (or enterprise) studies, may help to eliminate operationally or economically unsuitable sequences. Simulation studies and the use of computer technology must be based on reliable data gathered in the field; their use places great responsibility on the researcher for obtaining the primary data.

Studies of management systems are needed that explore continuous and mixed cropping systems. The management systems should reflect flexible and imaginative choices of crops, animal species and genotypes. They should be designed to provide inputs that utilize to the fullest that proportion of the year and of land, water and radiation systems that will yield the most in terms of the economic, human and technical goals of the region. In wetter areas, where population density creates a demand that warrants it, two or more short season crops can be grown in the same year. Some indigenous systems already approach continuous cropping with crops overlapping in time. Mixed cropping is also widespread and may make possible a better use of labor and offer other advantages in the future.

In summary, research at the level of the farm must consider institutional and human, as well as technological, constraints. It is on the farms themselves that the biological and physical systems interact with social, political and economic systems. Physical constraints, for example, may result from difficulties in the supply of water or the presence of pests and diseases. Often as debilitating are the constraints imposed by the social environment, such as inability of the local infrastructure to provide improved factors of production or to move products to markets, or such as food prices that are so low they do not cover production costs.

In the organization of agricultural production units, biological and physical systems should be closely linked to the political, social and economic systems. Members of the agricultural research teams should include anthropologists to assure that the technical research results really meet the needs and opportunities of the rural society and that the farmer's opinions and reactions are taken into account.

INPUT DELIVERY SYSTEMS

Everywhere in Africa, new farm technologies are requiring new factors of production–inputs such as improved seed, fertilizer, irrigation water, pest control measures and machinery. These factors must be delivered to the right place in the right quantity at the right time and at the right price to encourage rather than restrict their use. Entire systems are necessary to do this, but they are usually absent or poorly developed in Africa.

Much research is needed to determine the appropriate roles of public and private enterprise in input delivery systems. Trained governmental manpower is scarce and expensive, and government has other important uses for it. Much hard and detailed work, some of it unskilled, must be reliably done to deliver inputs–sometimes to as many as 100 or 150 African farmers per square mile of cropland. Information about and instruction in the use of new materials and methods as well as proper incentives must accompany physical inputs, which means that extension, price support, taxation, subsidy programs and other manifestations of agricultural policy must be closely related to input delivery systems. Where machinery is involved, spare parts, repair services, lubricants and fuel are needed, as well as training in the care and operation of the equipment. Delivery systems that use labor-saving equipment must be related to policies that govern industry, migration, and population control.

Among the most important but least studied inputs to African agriculture is power. Studies of labor must encompass all aspects of the power needs of a rural community and not focus entirely on topics, such as the migration of the labor force leading to the generation of nonfarm employment or the consequences of mechanization. More needs to be known about the specific changes in technique that lead to disinvestment in traditional capital, including farm animals, and investment in durable equipment. Both Africans and non-Africans are now tackling the theoretical inadequacies in this area.

For land, as well as labor, there are many substitutes and complements, the use of which increase the effective supply of land. Fertilizer is probably the most important of these. Land that is too wet or too dry is complemented by systems–all too rare in Africa–to drain or irrigate it. Other complements include elimination of pests and diseases such as trypanosomiasis, schistosomiasis, malaria and river blindness from otherwise potentially productive areas.

Though most agricultural problems in Africa involve land tenure, research in this area may easily be overemphasized; it is but one aspect of the problem of designing better agricultural systems. Much careful work—technological, economic and sociological—is needed on systems for producing and distributing fertilizers, irrigation water, vaccines, herbicides and other agricultural inputs.

Credit and cash are needed to purchase modern inputs and capital goods. Considerable investigation is needed into how much capital can be produced in the agricultural economy with underemployed labor, underutilized land, and traditional equipment and power sources that are partially idle during all or parts of the year. Some agricultural economies generate over half their capital under such conditions. Such self-generated accumulation and reinvestment of capital is probably more immediately important in Africa than money flows through capital markets and agricultural credit institutions, though the latter can obviously help farmers buy industrial inputs and equipment.

PRODUCT PROCESSING AND DELIVERY SYSTEMS

Farmers will not use improved production systems, however excellent biologically and however well-supported by input delivery systems they may be, unless the resulting products can be guaranteed a reliable market. Successful marketing requires an effective delivery system to assemble, store, process and transport farm products (industrial raw materials as well as food) to foreign and domestic consumers. In the immediate future, the volume of commodities available for marketing off the farm may easily double or even quadruple as a result of population growth and migration to the cities. This may occur even if the total agricultural output increases no more than 10 percent. At the same time the increasing availability of higher incomes and better education about what constitutes good nutrition can greatly change the marketing and processing services which the consumer may expect.

Product handling systems range from simple, local ones that transfer a producer's surplus product to local consumers (see Figure 1) to complex systems that process commodities and move them thousands of miles or store them, often in highly sophisticated ways, for long periods.

Markets for Africa's export crops are rather well-developed; domestic markets for foodstuffs traded locally appear less developed. The study

FIGURE 1 African market place, Ejura, Ghana.

of staple food marketing by the Food Research Institute of Stanford University (Jones, 1972) indicated, however, that African foodstuff markets are more effective than is commonly believed. But whatever the crop, in general, the development of well-integrated market systems within the continent is discouraged by (1) heavy transport costs, which result from poor roads; (2) taxation in the case of export crops, which interferes with regional specialization; (3) inadequate consumer incomes and the consequent lack of purchasing power; (4) restrictions on trade across national boundaries; and (5) inadequate national market systems for food crops.

Careful research to discover and to develop remedies is needed. Such attempts at aiding domestic markets as marketing boards, price ceilings for consumers and rationing have not proved satisfactory in the past. In developing and largely agricultural countries, such as African nations, it would seem that outside subsidies may be necessary in order to provide incentive prices to producers and cheap food to consumers. The well-developed export market also faces problems. Unwise taxation of export crops has been mentioned. In addition, many semipublic marketing agencies are unable to market such commodities as cocoa, palm oil, groundnuts, rubber, tea and coffee to best advantage in the complex economies of Western Europe and North America. These same agencies for export crops have run into difficulties domestically by not being properly related to input delivery systems for credit, industrial inputs and machinery.

RURAL AND AGRICULTURAL COMMUNITY SYSTEMS

Agricultural change in tropical Africa is at least as much an affair of the district and the local community as it is of the farmer and farm. Community systems, or local agencies of the central government, supply such prerequisites for agricultural growth and improvement as roads, regulatory services (contract enforcement, standardization of weights and measures, market regulation, product inspection and grading, etc.), communication (mail and often telegraph, telephone, radio and television), electricity, research facilities and extension services. As changes in agricultural production systems involve increased use of the facilities and services furnished by the local infrastructure, improvements in the infrastructure and in the institutions to serve it must be provided.

NATIONAL AND INTERNATIONAL AGRICULTURAL SYSTEMS

Just as the farm management system interacts reciprocally with the larger system of the community, so the rural community is related to still larger systems. Perhaps the most important of these is the agricultural sector of the economy, which is now a basic planning unit for many agricultural development agencies, including the Food and Agriculture Organization of the United Nations (FAO) and the U.S. Agency for International Development (USAID). At even higher levels of aggregation are the national economies, regional organizations and world markets.

Most African countries have central planning agencies that deal with agricultural industries and sectors. They are, in turn, assisted in their tasks by ongoing research and special studies undertaken by public and private agencies of various sorts–domestic, foreign and international. Unfortunately some of the comprehensive national development studies coming out of these agencies have paid little attention to technical aspects of agricultural development.

The design, analysis, execution and appraisal of agricultural policies, programs and projects constitute an important field of agricultural research at the national level. Though this kind of work is sometimes classified as economic, its nature is practical, and therefore it is more properly regarded as multidisciplinary. The mix of disciplinary competencies required varies from one policy problem to the next, from one program problem to the next, and from project to project.

Systems studies must consider the effects of different plans for the agricultural sectors on income distribution, employment, the generation of effective demand for food and the nutrition levels of individuals. Population policies will figure importantly in such studies for their effect on the balance between food production and consumption.

The succeeding chapters examine two broad areas, or aggregations of systems–soil and water management (Chapter III) and the production and protection of crops and livestock (Chapters IV–XIV). The second area is extensive; hence, it is divided into several chapters for easy reference. There follows a discussion (Chapter XV) of systems studies themselves and their place in African agricultural science.

III

Crop Environment, Soil and Water Management

An agricultural system begins with the crop itself and attempts to arrange for it to make the most of the primary natural resources of radiation, water and soil. The agricultural capacity of tropical soils and their ability to support intensive agriculture and to produce high yields of row crops has often been questioned. As knowledge of these soils improves, however, attitudes about their worth are changing. Research emphasis is now on the need to manage the soils in conjunction with the complex physical environment and involves in-depth studies of African soil and water resources. Unless the potentials of African soils are wisely exploited, crop production and livestock management in many areas will be marginal at best and will often fail.

CROP ENVIRONMENT

The natural environment for crops in the tropics is profoundly different from that in most temperate regions and this bears significantly on African soil and water management. Consideration of environmental factors is especially important in the transfer or adaptation to the tropics of agricultural technologies developed elsewhere. The qualitative differences are now moderately well understood (if not widely taught), but for successful practical farm management it is necessary to have more quantitative information about the dynamic nature of the tropical environment in relation to crop growth.

In tropical Africa, radiation levels and temperatures are reasonably high throughout the year and often it is the availability of water that is the limiting factor in crop growth. In the tropical region the soil–water regime is the "mirror image" of the situation in the temperate region: Annual crops are sown into soil newly moistened on the surface but otherwise hot and dry; then during the critical growing season, the soil profile fills with rain water, leaching off nutrients as the water drains off. In the temperate regions, the soil profile starts wet and cold and dries out over the season so that less leaching occurs during the growing season. Any attempt at devising patterns of efficient soil and water management and fertilizer application for Africa must begin within this framework.

While more intensive special studies are required for many crops, the quantitative specification of the macro-elements of the crop environment is now obtainable from relatively simple meteorological and soil measurements, which should be routine at all major research stations. Such specifications are a facet of crop research that has been neglected in the past.

SOIL MANAGEMENT

Current Facilities

The National Academy of Sciences/National Research Council, recognizing the importance of soil management, set up a Committee on Tropical Soils. The report of this committee, *Soils of the Humid Tropics* (NAS, 1972), deals in detail with research needs with regard to soil description and assessment and the management of soil nutrients.

Since the end of World War II, Africa has been the scene of a whole series of pedological surveys, pedogenic studies and soil classifications. This research was undertaken by the Office de la Recherche Scientifique et Technique Outre-Mer (ORSTOM) (see "International Agricultural Research Institutions," Chapter XVIII), Institut National pour l'Étude Agronomique du Congo (INEAC) and the network of British research centers. Thanks to this work, Africa became the first continent in the world to possess a modern soil map at a scale of 1:5,000,000. The map has inspired the Food and Agriculture Organization (FAO) to develop a world soil map. Simultaneously, soil maps have been drawn for individual countries at a scale of 1:1,000,000, and locally at a greater scale for regional planning (1:500,000 to 1:100,000) or for practical applications (1:50,000 and more). Research on the origin and classification of African soils is under way at Kwadaso, Ghana, and at other research institutions throughout the continent, especially those of ORSTOM.

Most, if not all, of the countries of tropical Africa maintain research units dealing with soil management. A recent United Nations Education, Scientific and Cultural Organization survey (UNESCO, Science Policy Division, 1970) lists 179 research centers at which some sort of soils research is being conducted. At Rokupr in Sierra Leone the peculiarities (extreme acidity, for example) of the soils in mangrove swamps where rice is grown and their effect on rice production have been studied. This research was undertaken by the West Africa Rice Research Station (see p. 47) in association with research workers from Rothamsted Experiment Station in Britain. A soil research team investigated the characteristics of the soils of Zaire at Yangambi and at the associated network of stations of INEAC. The improvement of soil fertility for cocoa production is being investigated at the Cocoa Research Institute of Ghana (CRIG) in Tafo and at the Cocoa Research Institute of Nigeria (CRIN) at Gambari near Ibadan. Oil palm production research is under way at the Nigerian Institute for Oil Palm Research (NIFOR) in Benin.

In the savanna zone of West Africa, important studies of soil conservation practices have taken place at the Institute for Agricultural Research (IAR) of Ahmadu Bello University in Nigeria, as well as at several research organizations in the French-speaking part of the region, primarily in Senegal and the Ivory Coast. Studies are under way at IAR, at the ORSTOM center in Ivory Coast and elsewhere in ridging, in mulching with stubble and in providing protective cover against the destructive impact of raindrops. Such soil cover may also have very significant influences on moisture conservation and temperature in the rooting zones. Water will percolate better through the soil if after a long dry season, the hard soil crust has been broken prior to the rains.

In East Africa, similar studies of soil erosion have been carried out at Namulonge in Uganda, Mpwapwa in Tanzania and Henderson Research Station in Rhodesia, while soil physical studies at the East African Agriculture and Forestry Research Organization (EAAFRO) in Kikuyu, Kenya, have concentrated on the effects of tillage practices on soil structure and crumb stability. The Kafue Flats in Zambia, whose physical structure is quite poor, have received intensive investigation stimulated by plans to develop a polder scheme for using Kafue River water to irrigate crops.

Future Research Needs and Opportunities

At present, coordination and correlation of various systems of soil classification have been satisfactory in the broadest categories. Much more needs to be done at detailed levels of classification to provide better extrapolation of research investigations, especially in soil management. Soil survey work should be broadened into land use surveys.

In soil conservation, the paramount need is for effective administrative leadership and wider application of proven methods. A few new problems, particularly in the area of erosion, deserve study and require the development of new methods—for example, the hazards of erosion in newly opened land. A strong case also exists for a carefully coordinated series of experiments, carried out in several countries, to compare techniques for controlling erosion used under different ecological conditions. Either the Scientific, Technical and Research Commission of the Organization of African Unity (OAU/STRC) (see "International Agricultural Research Institutions," Chapter XVIII) or the Association for the Advancement of Agricultural Sciences in Africa (AAASA) might be a convenient coordinating agent. Another type of soil conservation practice that requires more extensive investigation is the one just mentioned of maintaining cover to protect against rain and temperature extremes and to improve nutrient retention and recirculation.

Tillage operations used for seedbed preparation and weed control may have considerable effect on water conservation, soil erosion and fertility; they require careful study. Intensive work is needed on methods of lessening the number of operations required for cultivation. One such method, the use of herbicides by small farmers, is already being studied in Senegal, at Ahmadu Bello University and at EAAFRO. Work with herbicides for small farmers must be much more widespread than indicated. Research needs to be strengthened on this and other methods for reducing the drudgery of weeding operations and improving the timeliness of cultivation practices.

Scope is limited for improving the hand tools which small farmers use for primary cultivation and weeding, but opportunities are great for devising simple, inexpensive machinery for planting, applying fertilizers and pesticides, and for harvesting. It is difficult at present to make the operation of tractors economic in small farming situations, but the Centre d'Études et d'Expérimentation du Machinisme Agricole Tropicale (CEEMAT), among others, has done very useful work on ox-drawn equipment (see Figure 2), which should serve as a basis for further investigations where capital is short in supply and simple implements are needed.

FIGURE 2 Oxen pulling a log to till the soil.

Special attention should be given to the large areas of farmlands that are idle or underutilized under present management practices. In addition, the organization and operation of successful large-scale farms and smallholders' operations, and the mechanization of small-scale farming, may need to be examined.

The most important problem of soil management in tropical Africa is how to improve soil fertility and crop production under intensive farming methods. To attack this problem, extensive research is required on the physical, chemical and biological properties of the soil. Empirical solutions, e.g., simply adding major nutrients to the soil, will not suffice. The major chemical factors responsible for the accumulation and disappearance of organic matter in the soil must be explored; studies on the role of iron and aluminum oxides in tropical soils are needed. The contribution of the bacteria species of *Rhizobium* to the production of nitrogen in symbiotic relationship with legumes is a fruitful area for biological research. The addition of nitrogen to the soil by other natural means also requires study.

Soil fertility will vary from locality to locality, but detailed studies of the three main zones would still be useful: the tropical forests, where leaching is virtually continuous and excessive; the savanna zone, where leaching is regular and limited in time; and the semiarid rangelands, where leaching is infrequent and irregular. Several countries (Ghana, Ivory Coast, Nigeria, Senegal and Kenya, for example) could form adequate multidisciplinary teams to seek answers to these problems, and each of these countries could provide a good base for an external team. Among the international institutions with a capacity for such studies (see "International Agricultural Research Institutes," Chapter XVIII), are the International Institute of Tropical Agriculture (IITA) in Nigeria and ORSTOM in the francophone countries, where multidisciplinary teams are already formed. Studies of the hydromorphic soils at the IITA site are an example of crops and soil research integrated to study utilization of this land that is underutilized in African agriculture.

Land is an important social asset with strong emotive overtones, and it would be idle to suggest that soil management problems can be solved by the application to land use of research from the natural sciences alone. Economic issues—for example, those centering on expenditures for soil conservation measures or on investments for long-term maintenance of soil fertility—bear directly on soil management. And, inextricably linked with the economic issues are the social questions of land tenure and value systems. Socioeconomic research, therefore, must go hand in hand with conventional research in soil science.

WATER MANAGEMENT

Background

Availability of water is the limiting factor in crop production in many parts of Africa. Rainfall is variable and evaporation is high because of low relative humidity, high temperatures and high winds. Perennial crops in some areas can use as much as 2,500 mm (98 in.) of rain a year, and even at an altitude of 2,100 m (7,000 ft) in Kenya, forest trees and tea use 1,500 mm (59 in.) a year. Rainfall is adequate for successful perennial or annual crop production in some areas of Africa; in others, not cultivated, or at best supporting range grazing, rainfall is inadequate for a wide range of land uses without recourse to expensive large-scale irrigation developments. Often it is necessary to select a crop or breed or variety that matches the climatic environment—a short season crop where the period of favorable water balance is short-lived and a longer season crop where the favorable period lasts longer. To define the growing season quantitatively is important, for the first aim of water management should be to use the rain where it falls to the best advantage for crop and animal production.

Much has been learned in the past decade about the relation of crop water requirements to meteorological parameters. The pattern of water requirement for evapotranspiration can now be computed reasonably accurately from climatological observations and from data on crop morphology, planting density and length of season. The storage capacity for moisture within the root range may be important if water is likely to become limiting. If the pattern of water requirements for different crops is known, the crop or combination of crops can be suitably matched to each environment with a judicious margin for safety (success in 4 years out of 5).

In the drier parts of Africa, the collection and processing of meteorological data is the most important step in providing a basis for logical water management. The data must be obtained from a network of sites in each country sufficient in number to give adequate information on seasonal evaporation rates and rainfall patterns. A combined project of UNESCO, FAO and the World Meteorological Organization (WMO) has carried out valuable agroclimatological studies of the semiarid area in West Africa south of the Sahara and in the highland areas of East Africa. This group might be the most suitable one to continue this type of regional survey and study.

Routine computations of the water balance in a crop should be carried out for all experiments to ascertain whether, in addition to the main treatments imposed, water stress is likely to influence yields. In drier areas, soil management practices that prevent loss of rainwater through surface runoff and new cultivation techniques must be tested on different soils. For wetter areas, adequate drainage in the rooting zone is essential, and special measures are necessary to ensure this.

Some research has been carried out in Africa on water balance, but very little is under way at present except for studies of surface drainage in very heavy clays. Though drainage techniques are comparatively well understood, certain soils in many areas present special problems, the dark clays (Vertisols)* being one example. However, some areas with problem soils, e.g., the Sudan rainlands east of the White Nile, have good agricultural potential under natural rainfall alone or rainfall combined with dry-season irrigation; these areas merit a serious research effort. An alternation, even within a given growing season, between waterlogging with resultant poor aeration in the rooting zone and extreme lack of moisture, can occur on a variety of soils.

Research is necessary on the management and cropping patterns of soils that receive excess rainwater through runoff or "interflow" in

* A taxonomic class from the new soil taxonomy of the National Cooperative Soil Survey of the United States: U.S. Department of Agriculture, *Soil Classification, a Comprehensive System, 7th Approximation* (Washington, D.C.: U.S. Government Printing Office, 1960).

addition to, or as an alternative to, engineering studies of drainage and other compensatory measures for excessive saturation.

Lack of water often seriously limits range utilization by livestock; areas other than range areas may be badly over grazed because of concentration of stock at isolated watering points. Many methods of developing range water for livestock are known, but the selection of a suitable method for a given situation in Africa often calls for careful socioeconomic research in addition to technical water engineering. This aspect should not be neglected.

The research problems associated with irrigation rest not only in soil and water management but also in selection and intensive management of economic crops, in control of special pest and disease problems, and in social ordering and management of schemes. While the FAO Indicative World Plan (IWP/FAO) does not give irrigation research high priority (FAO, 1969a), African governments do.

In areas where it is desirable for economic or other reasons to introduce a system of irrigated agriculture, the water must be used as efficiently as possible within the management framework. The two key factors are the crop's total water requirement and the irrigation interval. The water requirement can be computed from meteorological observations, although extra amounts may be needed if there are salinity problems. The irrigation interval is a function of the plant's ability to withstand periods of mild water stress without loss of yield. Local trials, following on a review of the literature about the plant, will determine its ability to do so. International or regional irrigation efforts are not particularly appropriate for either topic; yet the movement of water onto the fields should require only local adaptations of proven techniques. A great deal of *ad hoc* experimentation on control of irrigation water is carried out on individual irrigation schemes in Africa as managers strive to engineer an efficient system for particular circumstances. There are few research centers for irrigated agriculture and, in these, water management is only part of the research complex. Many of the largest stations are at Wad Medani in Sudan and in Egypt. South of the Sahara, the principal research centers are at Ahero in Kenya, Kpong in Ghana, Richard Toll [Institut de Recherches Agronomiques Tropicales et des Cultures Vivrières (IRAT)] in Senegal, Bouaké (IRAT) in Ivory Coast, and at Dangwa, Malawi.

Land management in the catchment area of streams and rivers can have a profound effect on the seasonal and total flow of water. In such areas too little attention has been paid to inadequate precipitation during the "wet" season—a major cause of reduction in crop yield. Little is known quantitatively about the effects of land use changes on streamflow, and long-term investigations should be carried out. Land use is often an interest of several government ministries, and some independent body is needed to establish cooperative, unbiased studies. EAAFRO achieved this cooperation in East Africa, and further studies of this type should be initiated.

Research Capabilities and Needs

UNESCO lists approximately 70 institutions in Africa that are involved with a type of agricultural hydrology study. To these one may add a variety of *ad hoc* research projects that have been undertaken primarily to gain a better understanding of the influence on a region's ecology of large man-made lakes (for example, those created by the impoundment of the Volta River in Ghana at Akosambo, the Niger River at Kainji, Nigeria, and the Zambesi at Kariba, between Zambia and Rhodesia). One comprehensive study has been an analysis of the capabilities of Lake Victoria's watershed to yield water for irrigation. But these studies are only a beginning compared with what is needed before the potentialities for water conservation and utilization in Africa can be fully understood.

The main centers of water management research in Africa are in Kenya (EAAFRO, East African Meteorological Department, National Board), Malawi and Zambia (Agricultural Research Councils), Nigeria (Ahmadu Bello University, University of Ibadan, and IITA), Ivory Coast, Senegal and the Malagasy Republic (ORSTOM and IRAT). The FAO/UNESCO/WMO agroclimatological group should be encouraged to coordinate research in this field.

CONCLUSIONS AND RECOMMENDATIONS

Soil fertility and soil–water management have high agricultural priority for research. They play key roles in maintaining or improving production within existing farming systems; their projected role in the intensive farming systems of the future is even greater.

The Committee reinforces those recommendations of the NAS Committee on Tropical Soils that bear upon conditions in Africa, and *recommends that teams of scientists be supported at national and international levels.*

- *to bring about better coordination of systems of soil classification among the nations*, building upon the extensive information extant in this area of research on African soils;

- *to develop appropriate methods of soil conservation* under the auspices of international cooperating bodies such as OAU/STRC, AAASA, IITA, etc.;
- *to work on the physical, chemical and biological properties of soils*, in order to achieve a thorough understanding of the factors which influence soil fertility in tropical conditions and satisfactory soil and crop management, not only for systems of farming characterized by shifting cultivation, but for those where crops are produced under intensive farming as well;
- *to improve the total nutrient cycle of crop production in each of the three main rainfall zones—Sahelian, Sudanian, and Guinean—with special attention to management of the nitrogen cycle;*
- *to improve cultivation practices especially in small-scale farming operations*, with emphasis on increasing soil fertility, conserving water and reducing erosion; reducing labor requirements for weeding and cultivating; and improving management and timing of cultivation operations;
- *to develop for small-scale farmers new techniques and inexpensive mechanized equipment at the appropriate technology level;*
- *to gather information on seasonal evaporation rates (averages and probabilities) and on rainfall patterns for use by governments and research workers in planning water management and cropping cycles.* The FAO/UNESCO/WMO agroclimatological group might assist in this objective;
- *to conduct long-term investigations on the effect of land use on streamflow in catchment areas.*

IV

Cereals

Cereal grains–wheat, teff, sorghum, millet, maize and rice–provide half or more of the daily supply of calories in the less humid African countries. The average daily consumption of cereals per person in Africa is 330 g. The nation with the smallest per capita average is Zaire, with 70 g; Malawi has the largest with 571 g (FAO, 1971a). The countries with large average consumption are those in which sorghum and the millets are the predominant food crops. In the same countries the daily intake of protein from the cereal source averages more than 40 g. This would represent half or more of the daily requirement if distribution were equal and the quality satisfactory. Essentially the same pattern of protein intake prevails where maize is the major food cereal. A cereal diet that provides sufficient calories will generally also supply enough of the essential amino acids, lysine excepted, to meet protein needs.

Patterns of food consumption differ by economic level as well as by geography and culture; these patterns influence crop production. Wheat and rice are status cereals. Economically justifiable opportunities for expansion of wheat acreage are limited in Africa south of the Sahara. Good conditions do exist for rice, however, and expansion of rice acreage will lessen the heavy current burdens on government foreign exchange resources. Maize, sorghum and the millets will continue to be important food crops for much of the population for years to come. Maize is replacing sorghum and the millets in those parts of the Sudanian zone where the soils are deep and fertile and rainfall reliable. The people there prefer maize as a cereal but have not yet developed good beer from it. Sorghum holds its own under conditions uncongenial to the production of maize–in drier regions and on heavy clay soils subject alternatively to drought and flooding; pearl millet (*Pennisetum*) maintains its position in extremely sandy soil where rainfall is erratic–those areas where famine is often serious and the food problem the greatest. The importance of maize, sorghum and the millets as feed crops will increase as livestock production moves from a nomadic to a more sedentary system; thus, the productive capacity for all these crops deserves to be protected and enhanced.

The early efforts to improve the cereals concentrated on the local land-races, except for varieties of wheat and to a lesser extent rice. Local varieties tend to be well-adapted to their specific niches, acceptable in quality, and resistant in some degree to the more important diseases and insect pests. These local types, however, tend to be rather unresponsive to fertilizer applications or other improved management practices, though this is less true for varieties of corn.

Sorghum and millet probably originated in the Sudanian zone of Africa around Ethiopia and Sudan. There, the genetic diversity of these species is great. Wheat and especially barley are also genetically diverse in the Ethiopian uplands. To date, collecting forays have taken place intermittently in Ethiopia, but a comprehensive review of genetic material from this region has not yet been attempted. Various organizations (among them FAO), together with the Ethiopian government and scientific personnel, have discussed the value of an international center to collect, maintain and preserve germ plasm from these and other important crops that apparently originated in the Sudanian zone.

Agricultural policy that determines the proportion of land used to grow basic cereal crops may affect human nutrition and economic well-being in an area. For example, policymakers can influence whether or not the production of upland rice for human consumption rises at the expense of maize and sorghums, which have superior protein content and quality and proven adaptation to the region. In this situation to opt wisely for maize and sorghums, however, need not preclude an expansion in rice production in the wetlands of the Nile Basin and of West Africa, areas not so favorable to the other cereals.

CURRENT STATUS OF PRODUCTION AND RESEARCH

Wheat

The major wheat-producing countries in Africa are Ethiopia, Kenya, Sudan and Tanzania. The 1969 production for these countries was

760,000; 162,000; 88,000; and 40,000 metric tons respectively (FAO, 1969c). Wheat consumption has been rising steadily, and this trend is expected to continue. But only Kenya is currently self-sufficient in wheat. For the 1962–1965 period, average annual imports of wheat and wheat products for West, Central and East Africa amounted to $28.6 million, $12.8 million and $11 million, respectively. Rising consumption will result in increasing imports unless research and development programs are markedly strengthened and production is increased.

Wheat requires cool weather during the tillering and early growth stages. These conditions are met during the summer season in the highlands of East Africa, in Ethiopia, western Uganda and Rwanda. In Kenya, both acreage and production per acre have been increasing since 1962. Expanding wheat production in these areas might simply require strengthening the research capabilities that are already international in character in Kenya and neighboring countries, and enlarging facilities for testing new varieties in the highland areas of Tanzania.

Wheat is grown as a winter crop in the Sudan where production is concentrated in the Gezira and Khashm el Girba irrigation schemes. Irrigation is also being used in Chad and other areas to expand production capacity.

Attempts to grow wheat commercially began in Kenya about 1910 with varieties introduced from Australia. The widely known black stem rust of wheat (*Puccinia graminis*) soon felled these varieties. Since then wheat production in Africa has involved a continual struggle to find and develop varieties that will yield enough to justify growing them despite the inroads of this and other rusts.

Rice

The consumption of rice per person is increasing in Africa, particularly near the rapidly growing urban areas. Except for the Malagasy Republic and Egypt, however, the continent remains a net rice-importing area. Rice of the species *Oryza glaberrima* has been cultivated for centuries in Africa, but most that is now raised derives from strains of *Oryza sativa* introduced from Asia.

Rice is grown under four distinct conditions: (1) as an upland crop; (2) in paddies in which rainfall is impounded by field dikes; (3) in mangrove swamps; and (4) in naturally inundated lowlands.

Upland rice accounts for at least two thirds of the total rice acreage in West Africa, where most of the rice is grown. This production system is limited to areas which receive regular and heavy rainfall during a 5-month period. Land is cleared, and after minimal preparation the seed is broadcast. Weeds are not a serious problem for a year or two after clearing. Declining soil fertility and weeds after two or more years require a shift to some other crop or abandonment of the field. Labor inputs are large relative to yields. The Casamance project in Senegal is of some interest, since it has demonstrated that under proper management upland rice can produce high yields with greater economic returns than irrigated rice, especially if amortization of capital is charged as a cost against the latter. High-yield varieties evaluated under irrigated conditions may alter this picture, and whether the practices developed in these projects will be generally adopted remains to be seen.

Irrigation with adequate water control is practiced on only a very small proportion of the total rice area of Africa. One such successful scheme is the 4,000-hectare Mwea–Tebere Irrigation Settlement Scheme in Kenya, where a single crop of rice is produced annually under controlled conditions. In the Malagasy Republic, rice growing could be expanded along the flood plains of rivers, but the investment required to build canals, embankments and drainage is too much for the ordinary smallholder. If such developments are to be undertaken, a government or some other corporate entity must act.

In Mali, the Office du Niger, operative along the upper Niger valleys after World War II, made vast efforts to produce rice under irrigation with French bilateral aid. Nigeria has also undertaken irrigation projects in the Midwestern State at Ilesha and south of Kano. The Northeastern State, with Food and Agriculture Organization support, has an irrigation development project embracing wheat–rice rotation, with wheat grown in the winter season under irrigation and rice during the rains.

One of several attempts to develop an irrigated swampland for rice production was undertaken in the 6,000-hectare Gbedin swamp in Liberia. In 1953 Liberia and the United States Foreign Operations Administration began a project designed to start with a 25-hectare tract, adding more land as experience accumulated. The project was reported as a success, but, though an intensive extension program trained a large number of people, the irrigation system of rice culture was not maintained. Later, heavy rains washed out the dams and canals, and the area reverted to the original swampland rice system. The United States Agency for International Development (USAID) attempted to revive the irrigated system, but this effort was also short-lived. The project has again been reactivated under the supervision of Taiwanese technicians.

High yields of rice can, of course, be obtained with proper management on irrigated tracts, but for satisfactory water management the whole of a given area must be handled as a unit and the cost of clearing land and building canals, embankments, and drainage ditches is great.

High labor requirements and relatively low returns once the system is in operation make it less attractive than the "slash-and-burn" upland system (see Figure 3) or the typical swamp rice production system. Moreover, until transportation and marketing facilities are improved and a more realistic price policy is developed, there will be little incentive for the smallholder to produce more rice than is necessary to meet his family's needs, especially as the labor cost is so large. To remedy this, collective infrastructures and area management must be developed. Nigeria, through prohibition of imports, has become largely self-sufficient in rice production. Yet, even in Nigeria, the internal price has risen to 2- and 3-times that of rice on the world market, even though the world market prices themselves are reported to be very high.

Taiwan development teams have been active for a number of years in more than 20 African nations. Many of these teams, which have since been withdrawn, established excellent standards of rice cultivation.

Rice production may be limited as much by the poor quality of the paddy (unmilled rice) and the low efficiency of milling as by transportation and marketing problems. Poor quality of the paddy results from the raising of mixtures of forms that mature at different times. When immature and mature grain are harvested together, drying, storage and milling become especially difficult. Poor conditions for harvesting and storage also contribute to poor paddy.

FIGURE 3 Fire as a tool in agricultural production.

Maize

Production of maize (*Zea mays*) is expanding. In the savanna zones of Africa, it promises to replace a sizable portion of the current sorghum area where dependable supplies of water prevail. Production of suitable varieties is also planned for the humid tropics; there maize will compete with the root and tuber crops. Maize already does well, of course, in Cameroon, Togo and Dahomey, where the savanna extends south virtually to the coast.

Data assembled from the West Africa Regional Maize and Sorghum Trials* indicate that maize responds more than sorghum to improved management through much of the Guinean savanna and southward. How widely these results can be extrapolated may depend on further critical examination under conditions of water stress. Maize yields of more than 7 tons/ha have been obtained in Zaria, Nigeria, 10.1 tons/ha in Bouaké, Ivory Coast, and 8 tons/ha in Dschang, Cameroon. Although sorghum yields have reached 5 tons/ha, rarely do they exceed 3.5 tons/ha.

The reasons for this difference are not well understood and it is possible that more intensive research may narrow this gap. Certainly sorghum is better able to cope with moisture stress than is maize. However, recent data from Nigeria indicate maize moisture requirements may correspond more closely to the average pattern of rainfall in West Africa than do sorghum (guinea corn) moisture requirements (Figure 4).

Improved management practices are often necessary to realize substantially higher yields with better varieties. The maize agronomy research program demonstrated this fact strikingly at Kitale, Kenya, where a combination of six practices increased yields some 400 percent to 8.03 tons/ha. The practices, in order of importance, were (1) early planting, (2) use of adapted hybrid seed, (3) dense planting, (4) adequate weed control, (5) nitrogen applications, and (6) phosphate applications. The same practices are important everywhere, though the relative rankings may differ. Agronomic research is required to show just how the practices should be followed.

Maize breeding has been under way for decades in several East African countries. The first work, begun in Rhodesia in 1932, produced a range of conventional hybrids, one of which (a single cross named S.R. 52) has performed outstandingly as far away from Rhodesia as Ethiopia. In 1955, Kenya started a new program that led to the production and release of synthetic varieties in 1961 and the first double cross and triple cross hybrids in 1963–all from Kenya Flat White maize material.

* Annual Reports (USAID/ARS, Major Cereals in Africa Project).

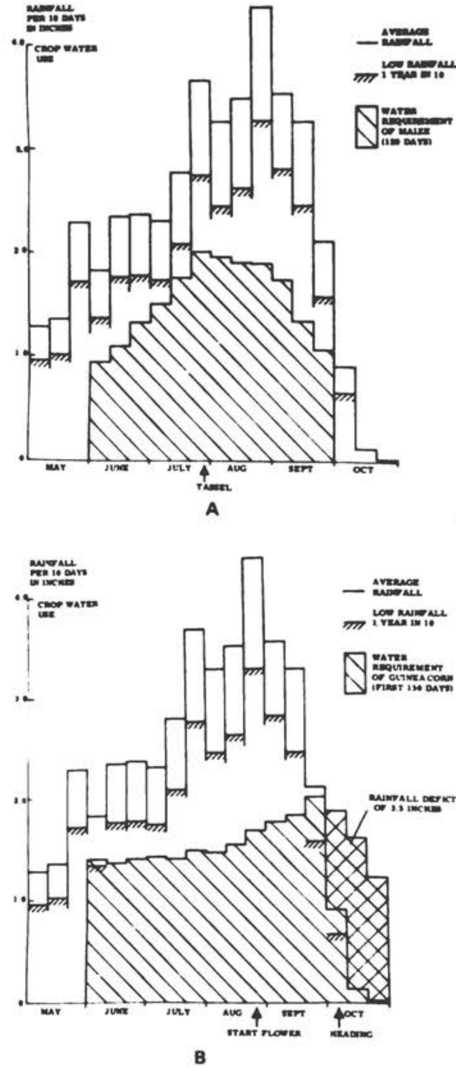

FIGURE 4 Comparative water requirements of maize (A) and sorghum (B) and rainfall available at Samaru, Nigeria. (Information derived from the *Agroclimatological Atlas* by Dr. J. M. Kowal and Mrs. D. T. Knabe, and hydraulic lysimeter studies at the Institute for Agricultural Research, Ahmado Bello University, Samaru, Nigeria.)

But the African maize possessed too narrow a genetic base to give sufficient vigor to the hybrids developed from it. Therefore the plant breeder in Kenya searched for material from Latin America, from Ecuador specifically, for varieties which would improve the crossing capability of Kenya Flat White maize. The search turned up an improved variety, designated 573, from a farmer's field in Ecuador. When crossed with Kenya Flat White it gave an advantage of 30 percent–

mainly by adding extra length to the ear. Out of these crosses came a varietal hybrid (composite) Kitale Synthetic II X Ecuador 573, which was released in 1963 to see what it would do in comparison with conventional (inbred line) hybrids. It became the highest yielder in many areas and, as an intermediate type hybrid, is now the one most commonly used.

At about that time (1963) the breeding program was modified to provide for the development of suitable composites, the initiation of population improvement studies and the commercial use of intercomposite hybrids. The use of hybrid maize increased from 120 ha in 1963 to 130,000 ha in 1970, and to 400,000 ha in 1973. By 1973 over 80 percent of the hectarage in hybrid maize in Kenya was planted by the smallholders.

A flexible breeding approach is now being utilized in the comprehensive breeding system practiced in Kenya. This involves the formation of broad-based composites and maize improvement through recurrent selection. The composites may be used as open pollinated varieties or in the production of intervarietal hybrids. Any yield increase resulting from the selection practiced should also be reflected in inbred lines derived from these populations wherever the use of conventional hybrids is economically feasible and desirable.

The comprehensive breeding approach, so admirably suited to the short- and long-term needs in Kenya, had a number of consequences for the maize improvement programs of other countries. Composites are being developed in Malawi and distributed there. Excellent progress in maize breeding has been achieved in Tanzania at Ukiriguru and at Ilonga, but commercial development has been limited because frequent changes in personnel have interrupted that program. On the other hand, until recently maize breeding in Uganda has been concentrated on inventory and varietal selection.

In 1966, the East African Regional Maize Trials began. These trials have resulted in a considerable body of evidence on the areas of adaption for the available composites and hybrids. Sorghum, the millets and wheat underwent similar trials, and the testing on all of these cereals (including maize)—the Major Cereals Project—is now administered as Joint Project 26 of the Organization of African Unity/Scientific, Technical and Research Commission (OAU/STRC). The countries now involved in the trials include Burundi, Zaire, Cameroon, the Malagasy Republic and Nigeria, as well as the East African countries of Ethiopia, Uganda, Kenya, Tanzania, Malawi and Zambia.

A program using extensive importations from the Caribbean area began in 1963 at Ibadan, Nigeria, under the auspices of The Rockefeller

Foundation. Changes in personnel interrupted the work, but it was continued by USAID, then by the Major Cereals Project, and more recently by both that project and the International Institute of Tropical Agriculture (IITA). One feature of the Nigerian research includes study of composite plants' development and improvement in Ibadan, Mokwa, and Zaria; a similar program was recently initiated in Ghana. In 1970 in Nigeria, IITA, International Maize and Wheat Improvement Center (CIMMYT) located in Mexico, USAID, and the Institute of Agricultural Research at Ahmadu Bello University, Zaria, instituted a cooperative program for maize research. In Dahomey, Upper Volta, Senegal, Cameroon, Ivory Coast and the Malagasy Republic, the Institut de Recherches Agronomiques Tropicales et Cultures Vivrières (IRAT) has worked for ten years on varietal improvement. In Zaire CIMMYT, IITA, and the Zaire government have initiated a cooperative maize improvement effort at the Keyberg station near Lubumbashi.

Sorghum

Fifty million or more people in Africa receive at least half of their supply of calories from sorghum (guinea corn). Indigenous to Africa, this cereal is grown primarily for human consumption as a porridge or in leavened bread or in beer. A type with white corneous kernels is preferred for flour, which is prepared by pounding the seeds in a mortar to remove the pericarp and further pounding or grinding to produce a fine granular powder. Some villages have small mills for grinding sorghum or various mixtures of sorghum with millet and cassava. A type of sorghum with brown seeds is commonly used for brewing beer.

Sorghum production reaches its greatest concentration in a belt south of the Sahara where the rainfall varies from 600–1000 mm (25–40 in.) or more per year and soil textures are relatively heavy. In West Africa, rain within the sorghum belt falls mostly during a single rainy season; some parts of East Africa have two rainy seasons. The rainfall patterns dictate the time of maturity of the varieties grown.

The upland soils of the Sudanian and Guinean savannas where sorghum grows tend to be leached, low in fertility and organic matter, and poorly buffered. Preparing the soil by hand or oxen does not permit efficient incorporation of plant residues; this may reinforce the widespread practice of removing the straw for use as feed or building material after the crops have been harvested. Applications of manure give yield increases that are usually large considering the quantities of nutrients actually supplied. In any event, the potential supply of manure is quite inadequate to take care of the need for nutrients, and mineral fertilizers must be used.

Sorghum yields on farms are generally lower than yields from experimental plantings on research stations. The difference may be caused in part by the varieties grown and in part by production practices. Crop production studies have concentrated on monoculture systems and practices, but sorghum and the millets are often grown in mixed plantings with legumes or other crops. This practice will certainly continue until an economically feasible alternative is developed. Except for recent research in Nigeria and Cameroon, little attention has been given to production systems involving mixed cropping. Such systems appear to offer promise of greater total food production with a corresponding reduction in the risk of crop failure. Moreover, an extension effort directed toward a more systematic mixed-cropping system would probably be more acceptable to peasant farmers than the monoculture recommendations have been.

The Millets

Like sorghum, the millets are mainstays in the diets of the people in the dry parts of Africa where subsistence farming supplies local needs. Along with many other crops in areas with uncertain water supplies, millets are expected to survive, not necessarily to thrive. Millets have demonstrated the capacity to yield well under experimental conditions, although in very wet situations they may yield less than sorghum or maize.

Two classes of millets are important in Africa–bulrush or pearl millet (*Pennisetum typhoides*) among other species and finger millet (*Eleusine coracana*). Bulrush millet, a cross-pollinated crop, is widely grown on light, sandy soils in single or mixed plantings where moisture is scanty or where the rainy period is short. Finger millet is predominantly self-pollinated. Though hardy, it needs higher humidity and a more stable water supply than bulrush millet. It is commonly grown as a first-rains crop in eastern Africa. Finger millet stores well under humid conditions. The small seed size makes it easy to dry in the sun, weevils seldom infest it, and it has been successfully combined by commercial farmers.

Teff

Teff (*Eragrostis tef*) is grown only in Ethiopia where it is the preferred food cereal (Figure 5). It tolerates poorly drained soils and occupies two million hectares of cropland.

FIGURE 5 Teff in the foreground, neug in the background (Jimma, Ethiopia).

RESEARCH NEEDS

A major need in cereal grains research in Africa is to broaden the germ plasm base of existing breeding programs. Establishing a center to collect germ plasm in the Sudanian zone would be a step in this direction. When breeding programs are adequately supplied with material, increased attention must be given to disease and insect control through development of resistant types or the judicious use of chemicals. Adaptation to specific sites, higher yields and better nutritional content should also receive attention.

A brief look at one significant advance in maize research will help explain how improved varieties are bred and why this advance is becoming a major research focus for that crop in Africa.

Half the protein in ordinary maize is zein, which is indigestible by man and nonruminant animals. But the commonly used varieties of maize contain little lysine, which is an amino acid—one of the building blocks of proteins essential for man and nonruminants.

In the early 1960's a team of researchers in the United States (Harpstead, 1971) discovered that a soft-kernel mutant of maize contained substantially less zein and about two-thirds more lysine than is present in ordinary maize. The recessive gene carrying this trait was called opaque-2 because the kernels, unlike ordinary maize, transmitted no light; it was given the number when catalogued years before. This opaqueness simplifies breeding work because it is easily spotted visually. Another mutant called floury-2 was also found to have this improved protein content.

Once the qualities of the opaque-2 gene were discovered (to follow it as the example), it was transferred to lines of maize adapted to particular localities. This was accomplished by backcrossing for five or six generations. First, ears of a local variety were fertilized with pollen from a plant bearing the opaque characteristic; though the resulting kernels were translucent, all carried the recessive gene. The opaque-2 gene could be identified in the following generation from the appearance of an ear of the plant when fertilized with its own pollen. When this plant had the gene, one kernel in four was opaque. This second-generation plant was also crossed again with the original variety, and when those carrying the gene became known the kernels without it were discarded. Offspring were crossed in the same way with the original variety for one or two more generations. The result was seed bearing virtually all the characteristics of the original local variety except for the opaque kernel and the high lysine content. Ideally this seed could be planted for consumption or, where hybrids were grown, used as a parent with another strain that had also been given the "high-lysine" gene.

Tests with "high-lysine" maize have proved its value in preventing protein deficiency disease in humans and as feed for swine, which have nutritional requirements similar to man's. In areas where people must obtain most of their proteins from maize, the significance of this development is great.

Maize

Work is under way to incorporate the opaque-2 gene into local African stocks of maize. An opaque-2 composite (a natural, fertile cross), developed by the USAID program in Nigeria, has been released for commercial production. However, when the people process mature maize grain into *ogi* for home consumption, the protein leaches out, leaving starch for the most part, so that they derive little benefit from the improved protein content of the original grain.

The opaque-2 characteristic is also being introduced into the composites under development in Nigeria, Kenya and several francophone African countries. If acceptable yields can be achieved, these new materials should reduce protein deficiency problems wherever maize is an important component of the diet.

Breeding with a species so diverse in varieties as maize can have many purposes besides improving food quality. Some have already been discussed in the section on maize production. Another is to develop strains resistant to diseases and insects.

Disease and insect problems of maize vary in Africa according to rainfall and temperature. At higher elevations, northern leaf blight (*Helminthosporium turcicum*) and northern leaf rust (*Puccinia sorghi*) are the important leaf diseases. In warmer areas, related species, southern leaf blight (*H. maydis*) and southern leaf rust (*P. polysora*), replace them. Stalk ear rots are also important as acreages and densities of maize grow.

Storey and his coworkers at the East African Agriculture and Forestry Research Organization (EAAFRO) were able to find strains of maize resistant to the principal races of southern leaf rust after it threatened to cause serious losses in West Africa in 1949 and the early 1950's (Storey and Howland, 1957, 1959). Rusts, however, have considerable genetic variability, and if a new race should appear serious damage could again follow. Lallamahomed and Craig, working at Ibadan, Nigeria, have reported a new gene system in maize that provides resistance to all the races of rust currently established in Africa (Lallamahomed and Craig, 1968).

The virus disease called maize streak, which is transmitted by several species of leaf hopper (genus *Cicadulina*), is of general and increasing importance. The vectors are widely distributed, and in some areas the disease may be a limiting factor for maize production. Storey found sources of resistance, but they have not been incorporated into local types. Another virus disease, maize stripe, has been reported from Tanzania and from tropical areas outside Africa, but no extensive research on it has been reported.

Africa has a multitude of stalk borers, such as species of *Chilo, Sesamia* and *Busseola,* that may attack maize, sorghum and the millets. Their importance may be expected to increase with an increase in intensity of production of any of these crops. Such work as has been done to develop resistance to or chemical control of stalk borers has taken place in Uganda and Kenya; further research on these pests is clearly in order.

In a discussion that focuses closely on such particular needs as breeding specific plants for specific purposes, it is easy to lose sight of other needs, including (1) facilities to produce and distribute improved seed, (2) closer integration of research and extension activities, (3) storage, transportation and marketing, and (4) adequate facilities for credit. Research applied to these topics will also be required.

Sorghum

The need for research on sorghum parallels that for other cereals in Africa, i.e., breeding plants for adaptation to changing farming systems, for better yields, for better nutritional quality, and for resistance to pests and diseases. Control of specific African pests, such as weaver birds (*Quelea*) and witchweed, offers an important challenge for research (see Chapter XIV). An immediate research goal is to establish the farming systems by which the subsistence farmers can derive the greatest amount of food from sorghum.

Considerable progress has been made toward assembling a comprehensive germ plasm bank for sorghum. A modest collection exists at the IAR in Zaria, Nigeria. An extensive collection, providing the genetic base necessary for continued progress in breeding, is projected. A systematic program is also needed to assay prevalent races for resistance to diseases and insect pests and to introduce this resistance into commercial types.

The worldwide success of turning hybrid vigor into production gains with maize is being emulated for sorghum in Africa. Here, too, if hybrid seed is to be produced on a commercial scale it must be done by using male sterile parents, a somewhat more delicate procedure than the one now in use to produce male sterile maize. If the plant to be fertilized produces fertile pollen, it may fertilize itself rather than receive the pollen from the plant the breeder wants as the male parent. Maize can be emasculated by simply removing the tassels from the top of the plant, but the analogous procedure is impossible on a large scale with sorghum because both sex organs are in the same flower. Fortunately, genes are available that will introduce male sterility to lines being developed as the female parent.

Several types of sorghum populations are under development in Senegal, Nigeria, Uganda, Tanzania and Ethiopia for superior grain quality, resistance to pests and other characteristics. Each population type has been separated into forms that will restore fertility and those that will not (nonrestorers), and is being subjected to selection for target characteristics. Genetic recombinations for height, maturity, and wild types of genes present problems, but not insurmountable problems. The hybrids produced in this program have consistently yielded more than the best improved varieties.

Breeding does not offer great promise for the control of sorghum's greatest predator in Africa, the red-billed weaver bird (*Quelea quelea aethiopica*). The enlarged glumes around sorghum grain, which make it harder for birds to get at the grain, fail to deter the quelea when its attack is heaviest, as in years when other native grasses it normally feeds on are in short supply. No method has yet been found to reduce the bird's numbers substantially, and its recurring predations account in part for farmers' planting maize even in areas where sorghum may be the more reliable producer. Control methods, such as blasting nesting sites, have thus far been ineffective in achieving a lasting reduction of the quelea population; though the Organisation Commune du Lutte Antiacridienne et de Lutte Antiaviaire (OCLALAV) has used such methods to destroy millions of these birds each year.

Sorghum is subject to attack by a wide array of diseases and insect pests. No valid estimates of losses are available, but in localized areas the effects of any one or more of these can be catastrophic. All of the known smuts occur in Africa. Losses due to kernel smuts have been estimated to be at least 10 percent per year. Sources of resistance to some species and races of these fungi are known, but little has been done to develop strains resistant to them. Ergot is widespread throughout Africa (caused by *Sphacelia sorghi*). Unfertilized florets are particularly susceptible to infection from this fungus, fatal to human beings in large quantities but valuable as a pharmaceutical in small dosages. The potential for disease infection may be a serious deterrent to the commercial production of hybrid seed. Native varieties possess fair-to-good resistance to the more important leaf diseases (anthracnose, sooty stripe, and leaf blight). Exotic types needed to expand the genetic base in other respects may, however, be severely damaged.

Witchweed (*Striga* species) may cause serious losses and under severe infestation may render land useless for sorghum production. Differential resistance to this parasite is known, and in combination with good husbandry and limited use of herbicides, this resistance can hold losses to acceptable levels.

Insect pests damaging to sorghum include sorghum midge, the shoot fly and stem borers. Progress has been achieved in the sorghum program at Serere, Uganda, in developing types resistant or at least tolerant to the shoot fly. Recurrent selection has been particularly effective in concentrating genes for the "recovery" type of resistance through better growth of the tillers. Productive studies on host plant resistance to stem borers have also been made possible by the development of artificial rearing techniques for some of the types of this pest.

Insects may also cause serious loss to stored grain. While the corneous types of sorghum are more resistant to weevil attacks, control is largely a matter of proper harvesting and storage procedures.

The Millets

As with other cereal grains, the research needs of the millets include broad-based germ plasm pools to provide greater opportunity for selection of disease-resistant varieties. Improved rotations and mixed farming systems that include millets are also needed.

Most of the effort directed toward improvement of bulrush millet has been in plant selection, which under controlled pollination leads to better plant types but not necessarily to increased yield. Some very desirable early-tillering types have been developed in Senegal where short-stemmed millets for use as cereals form the subject of a project carried out by ORSTOM and IRAT under an agreement with the Senegal government. A recurrent selection program in Uganda based on a procedure similar to that used with maize has produced significant yield increases after only a single cycle, according to preliminary data. Male-sterile plants that can be used in breeding hybrids have been developed. Workers in the Ivory Coast have made significant progress in using radiation as a mutagen to develop short-stemmed highly productive bulrush millet that lends itself to mechanized cultivation practices.

The diseases that attack bulrush millet are the same as or similar to those of sorghum. The main effort of a breeding program in Nigeria is to develop resistance to downy mildew (*Sclerospora graminicola*), ergot (*Claviceps microcephala*), and smut (*Tolyposporium penicillareae*).

Improvement studies on finger millet have been limited almost entirely to strain selection and evaluation. Two varieties have been identified in Uganda and are being multiplied for possible release. Breeding research is under way through controlled pollination. Radiation is being used to induce genetic male sterility; if this is successful, the sterility will be used to develop a random-mating gene pool.

Wheat

The story of wheat in Africa has largely been one of a race to stay ahead of the rusts. Continual research is necessary to develop varieties with enough resistance to permit production at an economic level. Without this research, wheat production could have disappeared long ago from the East African highlands. Since rust resistance is also a major concern in other parts of the world, African work must be integrated with related work elsewhere, especially through CIMMYT.

The rusts present are black stem rust (*Puccinia graminis*), which was formerly most severe at altitudes of 1,500–2,100 m (5,000–7,000 ft) but now is found over a greater span of altitudes; stripe (or yellow) rust (*P. striiformis*), which is most severe at elevations above 2,100 m (7,000 ft); and leaf rust (*P. recondita*), the distribution of which has always been fairly general.

The rust problem has held center stage and has left considerations of quality waiting in the wings. Research on quality has been limited to discarding items with poor milling and baking characteristics. Inherent quality, therefore, tends to be no more than average and is often reduced further by rust and other diseases. Relatively little fertilizer research has been attempted and, therefore, little is known of the effect of fertilizers on the growing plant and on the quality of the grain produced.

The popularity of wheat and wheat products prompts governments to press for research adapting it to new environments, such as the wadis of northern Nigeria on the southern fringe of the Sahara, where tomatoes and other crops grow luxuriantly on the residual moisture available in the soil (supplemented by irrigation) during the cool part of the dry season following the rains. Nigeria has planned an ambitious expansion of irrigation schemes in the northern states of this zone. Kano State alone has completed one year's work as of 1972, on a dam for supplying irrigation water to 70,000 ha. Here wheat is one of the most desired as well as one of the most feasible crops to grow. Intensive local trade in horticultural crops is likely to develop in this area but only on a minor part of the envisaged irrigation development; "Mexican" wheat varieties are very suitable for growing under these conditions.

Rice

As for rice, Africa has its own research problems, its own genetic stocks and its own orientation toward production. The upland rice culture of Africa (representing more than two thirds of the rice acreage on the continent) has not been satisfactorily studied; nor have the seemingly widespread opportunities in wetland production been sufficiently examined. Current information on rice culture including fertilization practices and weed control, is inadequate for the wide range of soils and diverse array of environmental conditions of African rice production.

African rice production prospects will be determined by a number of economic factors, notably: (1) the increasing world demand for rice which Africa can help to satisfy, (2) the capacity of the rice-producing areas of Africa to meet the competition from rice-producing areas elsewhere in the world, and (3) the ability of the areas in Africa to hold a competitive economic advantage over other crops which are produced in these localities. These economic factors will depend upon certain unique ecological and agronomic ones. For example, this crop must compete with other cereals in the dry areas of Africa and with roots and tubers in the wet areas. The maximum rice yield that can be expected in the humid tropics, where cloudy skies reduce the amount of sunlight reaching the rice plants and thereby impair yield, is still unknown. Much of this research could be initiated and supervised from a well-staffed regional center with a wisely chosen series of satellite stations.

Birds are a hazard wherever rice is grown, and they are especially serious where the crop is raised in small, isolated patches. No effective controls are currently available. Rodents are locally destructive, and suitable control measures must be developed. Stem borers also present problems.

Rice is affected by a number of leaf diseases and root and stem rots. The most widespread and damaging is rice blast (*Piricularia oryzae*). It is far worse under upland conditions than in paddies. Since this fungus is highly variable and many races are known, development of resistant types of rice is a difficult problem. Resistance has been identified in some types and is being transferred into locally useful varieties. Such work must continue since new strains of this fungus appear to develop and become established even more rapidly in Africa than in Asia.

Teff

A research grant from The Rockefeller Foundation has made possible a thorough collection of germ plasm at Debre Zeit in Ethiopia. Several hundred selections have been fully identified and characterized agronomically. Tremendous increases in yield have been reported from selected and cultivated varieties subjected to modern cultivation practices.

The potentialities of this crop and the problems within its restricted range speak for a modestly expanded program of breeding and agronomy. Because the floret is small and delicate at the breeding stage, however, efforts so far to emasculate it for production of crossed offspring have failed. Artificial and induced mutation breeding may prove more successful.

Teff production suffers from a number of major economic problems, but the plant itself possesses serious physical handicaps: It has weak straw, it competes poorly with weeds in the seed bed and, when ready to harvest, the seed shatters. This last characteristic impedes mechanizing the harvesting and threshing of teff.

RESEARCH CAPABILITIES

The research capabilities for cereal grains in Africa are, for the most part, well developed in comparison to those for other food crops. The exceptions are millet, which deserves a greatly intensified research effort, and the Ethiopian favorite, teff, which could use more exploratory research, though its appeal is likely to remain local.

Wheat

In wheat improvement, the strongest program in East Africa is at Njoro, Kenya. Begun during the colonial period, this work is well supported by the government of Kenya, with inputs in earlier years from The Rockefeller Foundation and later from the Canadian government. Equally important are the cash contributions of the farmer himself through a voluntary levy on wheat. The work at this station is well integrated in the world's wheat-breeding network. Rust-resistant varieties developed here have been the mainstay of East African production and have served as useful parents in breeding programs in the United States and at CIMMYT in Mexico.

Modern wheat research has been initiated in Ethiopia at the Debre Zeit Experiment Station and at Alemaya in conjunction with the development of the College of Agriculture at Haile Selassie I University (HSIU) in Harar province.

At Khartoum, Wad Medani, and stations farther south along the White Nile in Sudan, strong agronomic and breeding programs for wheat and other cereals have produced improved varieties.

Rice

For many years the most important center in the English-speaking countries of Africa for research on the production of rice has been the rice station at Rokupr, Sierra Leone, established in 1934. The program was reorganized and expanded, and in 1949 it became the West Africa Rice Research Station. Through this organization, close cooperation was established with Senegal, Gambia, Ghana and Nigeria, resulting in branch stations in the last three. Regional work was discontinued in 1962, and the program in Sierra Leone was transferred to Njala College of the University of Sierra Leone. Local funds were inadequate to maintain the previous level of work, and the rice research effort became largely a holding operation. Rice research in Africa suffered a severe setback as a result.

Between 1936 and 1962, improved types were introduced and distributed widely in West Africa. The production program in the Gbedín area of Liberia in 1953 was based on varieties developed at Rokupr. Similarly, the rice improvement program in Nigeria began as part of the regional effort and benefited greatly from the breeding and production studies conducted at Rokupr, and at the Federal Research Station at Badeggi, Nigeria. Nevertheless, African rice yields remain low, and much can be done to improve varieties and production practices. Ghana produces about half its domestic needs for rice, but the quality of the material grown needs to be re-evaluated; little pure seed is available.

Rice research in the francophone African countries and the Malagasy Republic is entrusted to IRAT by the governments of the countries concerned. The network of stations consists of two regional centers—Ivoloina, the Malagasy Republic, for irrigated rice, and Bouaké, Ivory Coast, for irrigated and rainfed rice—and secondary stations in Senegal, Niger, Mali, Ivory Coast, Cameroon and the Malagasy Republic.

IITA recently initiated breeding and production studies with paddy and upland rice. In its short history, IITA has produced yields of 8.4 tons/ha in the dry season and between 6 and 7 tons/ha of paddy rice in the rainy season. Upland yields range between 3 and 4 tons/ha. These results corroborate those obtained before by IRAT in its research stations. The IITA program is coordinated with that of the International Rice Research Institute (IRRI) in the Philippines and cooperates with the activities of the West African Rice Development Association (WARDA) headquartered in Liberia.

Large areas of Kenya, Uganda and Tanzania are well suited to rice culture, but rice research has not received high priority in continental East Africa and has, therefore, suffered greatly from a lack of continuity. However, locally selected varieties and better cultural practices have given quite satisfactory yields in the Mwea-Tebere irrigation scheme, and the rice research program at Makerere University in Uganda has made an auspicious beginning. A rice research program was planned by EAAFRO, but by the spring of 1972 the necessary review of research capabilities in the countries of the East African Community—Kenya, Tanzania and Uganda—was incomplete because of delays in recruiting researchers.

Maize, Sorghum and the Millets

Since the research needs of maize, sorghum and the millets are similar, it is advantageous to conduct research on these crops at common stations. In breeding maize, the goals and procedures are quite similar to those for the other crops, and often the same or similar pests attack the different crops. Housing research on them at the same stations not only is economical, but also provides an opportunity for intellectual cross-fertilization among specialists in different fields.

At present, Kenya has a particularly strong capability in maize at its Kitale station. It has received inputs over a long period of time from The Rockefeller Foundation, the British Overseas Development Administration (ODA), the United States Department of Agriculture (USDA), USAID/USDA Agricultural Research Service (ARS), the East African Community and other sources.

Across the continent in Nigeria, a strong maize research program exists at IITA in Ibadan. It is building a capable staff and is developing associations with CIMMYT in Mexico and the International Center of Tropical Agriculture (CIAT) in Colombia, which provide ready access to germ plasm from all areas of the world. Two equally strong Nigerian research programs are closely associated with IITA—one at Ahmadu Bello University at Samaru in northern Nigeria and the other at the Federal Department of Agriculture station, Moor Plantation, in Ibadan, where USAID, British and Nigerian scientists are cooperating under OAU/STRC Joint Project 26 (described below, under "Prospects for International Cooperation on Cereals Research in Africa").

In francophone West Africa, IRAT maize research staff in Senegal, Ivory Coast, Dahomey, Upper Volta and the Malagasy Republic are studying fertilization, cultivation techniques, local varieties of importance and hybrids. This work is also linked by Joint Project 26 and IITA. Here, as elsewhere, lack of facilities for producing and distributing seed must be remedied for production of improved maize varieties to succeed.

One of the most important centers for sorghum research in Africa is IAR with its main station at Samaru and a substation at Kano, Nigeria. Studies are under way on breeding pest-resistant strains with attractive qualities as food (absence of bitterness) and on the most desirable production systems (in which sorghum is grown in mixture with other crops). Another important center is the Uganda government station at Serere. It houses the EAAFRO sorghum project, which is developing hybrids for grain quality and resistance to insect pests. General sorghum research is also being conducted in Sudan at Wad Medani and the Sennar Abu Nàama research substation. Breeding and selection studies under the supervision and guidance of IRAT are concentrated primarily in Niger, Upper Volta and Senegal, where the main research station, Bambey, is located.

The only stations engaged in maize and sorghum research also having substantial programs in the millets are those at Serere, Uganda, and at Kano, Nigeria. Other significant research capabilities are found mainly at Bambey, Senegal, where the emphasis is on breeding and early-tillering types, and in Upper Volta at Farakoba, where radiogenetic selection of highly productive shortstemmed varieties is under way. The Kano station is investigating disease resistance, and the one at Serere is working on problems of hybrid production. Significant research has taken place at the Makerere University farm in Uganda and recently at the University of Ibadan in Nigeria on crossing bulrush millet with a related species, elephant grass (*Pennisetum purpureum*), to produce a hybrid grass for grazing superior to either species separately.

Teff

The addition of specialists in breeding and agronomy to the Ethiopian research program on teff and the provision of adequate funding would appear to be a sound investment.

PROSPECTS FOR INTERNATIONAL COOPERATION ON CEREALS RESEARCH IN AFRICA

No single country in Africa or in any other continent can finance and implement the detailed and extensive research that the cereal crops require. Regional centers have been evolving to fill these needs in part. Such centers have to maintain close liaison with national programs which have responsibility for extension, seed production, and distribution programs; development of transportation, storage, processing and marketing systems; and for general policy.

Regional centers and individual country programs share a number of responsibilities, for example:

1. training men and women in practical field research and in the "Green Revolution" outlook, which emphasizes motivation as well as scientific training;
2. organizing regional workshops, seminar conferences, and consultation visits;
3. conducting regional varietal and agronomic trials;
4. assembling and studying world collections of germ plasm for each important crop; maintaining such stocks in viable condition; improving them through recurrent selection; and distributing the resulting populations to interested countries for further selection or for commercial use;
5. establishing plant quarantine and introduction facilities adequate

to handle the large numbers of items required in effective breeding programs;

6. identifying sources of resistance to important insects and diseases and devising other control measures; and

7. expanding work on the evaluation of nutritional and commercial-processing characteristics of cereal crop produce.

Several organizations now pursue some of these objectives in Africa; OAU/STRC, IRAT, WARDA, IITA, and the International Development Research Center of Canada (IDRC) are cases in point.

OAU/STRC launched a cooperative research effort in 1964 on cereals called Joint Project 26. This project, scheduled to end in 1975, is supported financially by USAID and is staffed and supervised by USDA. It has two regional centers, one cooperating with IAR of Ahmadu Bello University (Zaria, Nigeria) and the Nigerian Federal Ministry of Agriculture (Moor Plantation, Ibadan) and the other with EAAFRO. The research staff includes geneticists, pathologists, entomologists, soil scientists and a cereal technologist—all giving primary emphasis to sorghum, maize and the millets. Regional trials have also been established for these cereals, and regular conferences for researchers are held in both East and West Africa, in French- and English-speaking countries.

The corresponding activities of IRAT, which serves francophone West Africa, have been covered in the earlier discussion of research capabilities.

WARDA was organized several years ago; it now draws support primarily from the United Nations [the U.N. Development Program (UNDP) and FAO], from USAID, from the Netherlands, from the United Kingdom and from the governments of the 14 West African nations in which rice production, though substantial, fails to satisfy the demand. Some countries spend as much as 16 percent of their foreign exchange earnings on rice imports, even though the ecological conditions are favorable for rice cultivation and the high-yield varieties that apparently are well adapted to West African conditions are available. Soil management, irrigation and water control, and lack of proper infrastructure constitute some of the limiting factors.

The governing council of WARDA first convened in September 1971, and its headquarters has been established in Monrovia, Liberia. A 5-year program of work has been mapped and 14 research projects, two development projects, and one coordinating project are being prepared in cooperation with consultants from USAID, IRAT, FAO, IITA and three member countries. The governing council held a meeting in May 1972 to consider a draft of the research and the training programs, and other matters. WARDA views its most important objective as the preparation of specialists and extension workers for national rice programs of member countries.

IITA was designed to serve the humid tropics principally. Among the cereal grains it gives special emphasis to rice and lowland maize, and it also specializes in soils, edible legumes, root crops, farming systems and socioeconomic studies. The institute provides opportunities for research and production training and sponsors seminars on topics of regional significance.

IDRC sponsors many specific schemes or projects in Africa. One is directed toward research on *triticale*, an experimental wheat-rye hybrid, in the highlands of Ethiopia. Another is to improve the gum arabic industry in West Africa.

The Economic Commission for Africa (ECA) provides still another vehicle for conducting cooperative research (see "Forming and Executing Agricultural Research Programs," Chapter XVI).

During 1972, the Consultative Group on International Agricultural Research (CGIAR) established the International Crop Research Institute for the Semi-Arid Tropics (ICRISAT) with its central site in India. The program of this institute will deal with sorghum and the millets vital to the agriculture of Africa, and with grain legumes, especially pigeon peas and chickpeas. ICRISAT also proposes to develop relay stations at established national research centers in Africa, which will greatly amplify the international research capabilities in these crops. Much of the basic research can take place on an international scale at that institute, but each of the producing countries will need to shore up its own research on these as well as other crops.

CONCLUSIONS AND RECOMMENDATIONS

Because of their central role in African agriculture the NAS Committee on African Agricultural Research Capabilities assigns top priority to the cereal crops for accelerated and expanded research. This research is essential primarily because improved quality grains with increased protein content will provide more nutritious diets for increasing numbers of people. But increased knowledge of the cereal crops and methods of their production also promise to (1) eventually supply feed grains to the developing livestock industry; (2) lower the production costs of staple foods and thereby make them more accessible to the African consumer, increasing demand for them; and (3) improve the economic welfare of the small farmers and, with them, the economy of Africa as a whole.

The kinds of research on each cereal will vary in accordance with the specific gaps to be closed, but *the Committee recommends that support for African cereal crop be directed toward*

- *training African agronomists, breeders, plant pathologists and entomologists to help man the existing research programs and enlarge such programs where necessary* (amplifying agricultural course work and research facilities at the African universities and promoting short-term training experiences for African agricultural personnel at the international centers, etc.);
- *improving communication between extension workers and researchers* to expedite the adoption of research results;
- *improving communication between researchers in different countries in the manner of the cereal worker conferences held under the auspices of OAU/STRC, Joint Project 26; utilizing AAASA when it becomes feasible to do so to facilitate sharing of information among scientists and communication between scientists and government officials or groups of farmers;*
- *improving post-harvest technology,* particularly in storage and milling, to preserve protein content for human and animal consumption; and
- *encouraging utilization of indigenous germ plasm by assembling, pooling and preserving collections of genetic stocks at certain strategic points on the continent*–Ethiopia, for example.

Specific research recommendations on each cereal crop are outlined below.

- On sorghum, *the Committee recommends expanding national capabilities (in plant breeding, especially) in research based on the network of multicrop stations extending from Senegal through Upper Volta, Niger, Nigeria and Sudan, and Ethiopia to Uganda in East Africa.* This research should focus on improving the yield and quality of this crop through a comprehensive review of the germ plasm available from indigenous sources, as well as through creation of hybrids and synthetic varieties using material introduced from abroad.
- On the millets, *the Committee also recommends intensifying crop breeding for their importance as dryland crops and for the potentialities they exhibit for increased yields and high quality protein content.* More-

over, recent investigations suggest that the millets may prove to be an important genetic source for interspecific crosses with elephant grass. These crosses are expected to produce a high yielding, palatable hybrid forage for animals with little risk of prussic acid poisoning. Sound scientific and technical reasons underlie the creation of strong national and regional programs in Africa on the millets, programs that can stand alone but which also will complement and supplement the work of ICRISAT.

• On maize, *the Committee recommends improving the quality of maize grown in the humid tropics and its potential as a food crop in the off-season* (the hunger gap after the root crops have been consumed and prior to the next harvest).

• On maize, *the Committee recommends analyzing the existing farming systems in the dry tropics to determine the factors which prevent the local people from utilizing the maize varieties with improved yield capacity already available in these areas.*

• On rice, *the Committee recommends a thorough review of the upland cropping system.* This will require special attention to the plant varieties, especially their competitive position *vis-à-vis* sorghum, the millets and maize. *The Committee recommends strengthening WARDA to provide regional rice development and training facilities and to reinforce the programs of rice improvement at national level in West Africa.*

• On wheat, *the Committee recommends sustained research on breeding varieties resistant to the various diseases that attack it, especially to wheat rust with its many variants and to septoria blight.* Continuing efforts will be necessary to weave the research efforts in Africa with those of the international research organizations—CIMMYT, for example—where mutual benefit accrues through interchange of material tested at numerous sites under different pest and disease loads.

Teff will require fundamental research, a knowledge of and experience in crossing techniques. As teff is important primarily to Ethiopia, these may best be developed at national level within that country.

V

Grain Legumes

Many grain legumes provide food for the African people, but this report focuses on the three outstanding ones–cowpeas (*Vigna sinensis*), pigeon peas (*Cajanus cajan*), and the common bean (*Phaseolus* species). Cowpeas are the legume most generally planted for food throughout Africa, but they are extremely susceptible to pests and their yields are low. Pigeon peas are also widely distributed, but more as a casual crop interplanted with other economic crops. They have a latent general potential as a food crop, which can supply the local people with more protein of higher quality. The common bean thrives in the highland areas of the continent, but it, too, is highly susceptible to pests and diseases, and the range where it grows well is restricted.

Two other grain legumes, soybeans and groundnuts (peanuts), have great possibilities as food crops. Many countries have a strong interest in expanding research on groundnuts and in developing a capacity for soybean production. Groundnuts are currently of importance as a food and commercial crop in the semiarid tropics, but it is unlikely that production can be extended profitably into the humid tropical areas where protein deficiencies are greatest. Soybeans are the main source of protein for human food in parts of China and other East Asian countries.

The main economic interest in these crops lies in the possibility of increasing oil production from them either for export or for domestic consumption without, however, overlooking their significance as major sources of protein for human beings and livestock. This report considers them with the oil crops.

The food legumes, along with the cereals, offer an avenue for improving the protein balance in the diet of Africans. In general the legumes have a better balance of amino acids than the cereals, and better still are combinations of the two.

The legumes as a class, however, pose certain nutritional problems. They may contain cyanogenetic glucosides, various enzyme inhibitors, and other factors that affect digestibility of the seeds. Because we know so little about the biological significance of these adverse features, breeders are working in the dark in attempting to eliminate or minimize them. A joint research program of IITA and the University of Durham, New Castle, United Kingdom, may clarify some of these basic questions.

The yields and prices paid to the farmer for food legumes are often low, making them less attractive commercially than the cereals as an agricultural economy moves away from a subsistence level. Little is known about their inherent yield potential, though careful management has brought moderate yields at experiment stations in India and the United States.

Flowering in grain legumes can begin very soon after germination and may continue indefinitely under favorable conditions. A very wide range of times to maturity is usually found within a species, and most grain legumes can therefore be grown over the whole range of tropical African climates. They are more characteristic, however, of the seasonally arid cereal-growing parts of Africa than of the more continuously humid and protein-deprived zone where the staples are starchy roots and tubers.

Surprisingly little botanical work has been done on these crops in Africa, though at Townsville, Australia, workers have carried out valuable analyses of the grain legumes of Africa. While considerable collections have been made in several cases, much taxonomic, genetic and cytological work remains to be done. The related wild species have hardly been studied at all.

Many grain legumes are attacked by stem borers and foliage-, pod-, and seed-eating insects. In some cases these pests also affect the sorghum, maize and cotton crops with which the legumes are associated in the drier regions. Storage problems are particularly common and serious in grain legumes.

CURRENT STATUS OF PRODUCTION AND RESEARCH

Cowpeas

Cowpeas, which probably originated in Africa, are now grown wherever the climate is suitable around the world. They are the most important food legumes grown south of the Sahara with 2.7 million hectares planted comprising 90 percent of the world's production.

Their most important use is in the form of dried beans for human food, with the residue used for stock feed. They are also eaten in the green seed and green pod form and as sprouted seedlings, and the tender green leaves are cooked as a green vegetable. The pea has excellent nutritive characteristics, with a crude protein level that can exceed 30 percent but averages 23 percent, 1.4 percent of which is methionine, an amino acid generally lacking in food legumes. There are no reports of antimetabolic factors or toxic components in cowpeas.

In Africa the cowpea is commonly interplanted with sorghum or maize, providing a late (and often small) pulse crop and possibly contributing some nitrogen to the system. The undersown cowpea also protects the soil from erosion. Cowpeas are usually sown, cultivated and harvested by hand.

The worldwide average yield is 385 kg/ha; the African average is 370. Yields exceeding 2 tons/ha have been reported from experimental plantings sponsored by USDA and USAID in Iran; yields close to 2 tons/ha have often been achieved in trials at IAR as well. Low yields result mainly from severe insect attack, use of varieties with small yielding potential, and poor crop management practices. Outside of a few isolated, sporadic attempts, there has been very little effort to improve production in Africa. Cowpea improvement, however, is becoming a major effort at IITA.

A germ plasm collection has been started at Moor Plantation in Nigeria, a world collection of cowpeas is being assembled at IITA, and another extensive collection is maintained at the Kano station of IAR. Both photosensitive and day-neutral forms are known, and there are four distinct types of growth habits: erect, semi-upright, prostrate and climbing. There are also many variants in pod form and seed color, the genetics of which have been studied in South Africa.

Few improved, high-yield varieties have been developed in Africa or elsewhere, mainly because little consistent breeding has been undertaken. Breeding studies are under way in Nigeria, Senegal and Uganda.

The rhizobia (the nitrogen-fixing bacteria that live in association with cowpeas) are widespread in Africa. They may undergo some varietal specialization about which little is known. Cowpea rhizobia are being studied in a joint project between the Rothamsted Experiment Station and IITA.

An appropriate form of cowpea could probably be found for any prescribed agronomic application, including multiple cropping at very close spacing in maximum output systems. Studies of the range of agronomic conditions under which cowpeas grow well will indicate the reasons for the current very small average yield of the crop and suggest ways of increasing output. The association of cowpeas with sorghum and maize should also be studied critically, since mixtures of this sort offer a potentially important practical means of managing soils effectively, particularly with relation to the nitrogen cycle.

Mildew, anthracnose, rust, viruses, bacterial diseases, nematodes and numerous insects attack cowpeas. Because of the problems associated with use of insecticides, development of resistant varieties may become the best long-term method of pest control. Breeding for resistance also appears to be the best way to gain control of diseases and nematodes. For these reasons it is important to build a germ plasm collection including the 60 or more wild species of cowpeas as well as the full range of cultivated forms. Used in a well-coordinated, multidisciplinary research program, such a collection would greatly assist other improvements as well.

Pigeon Pea

The pigeon pea (*Cajanus cajan*), native to South and Southeast Asia, is widely grown in East Africa as a minor crop—often somewhat casually—alone or mixed in plantings with sorghum or the millets (Figure 6). It is seldom (if ever) seen as a sole crop, except at experiment stations. At present, Africa accounts for only about 2 percent of the total world production with 3 percent of the area planted to pigeon peas.

Yields in Africa are quite low, averaging 380 kg/ha. Experimental yields of a local variety have exceeded 5,000 kg/ha in India, and in Puerto Rico researchers have reported yields of more than 7,000 kg/ha of green peas.

The present low yields are mainly a consequence of varietal characteristics, insect attack and lack of good management. Dramatic increases can be obtained by taking advantage of the fact that, while most varieties are long-duration types (300 days from planting to harvest) the ma-

FIGURE 6 Picking pigeon peas, Masaki, Tanzania. (Photo courtesy of Ray E. Ellis, Rapho Guillumette Pictures, New York.)

turity range can be as short as 120–150 days or even less, depending on plant type and on length of day in the growing area.

In comparison with other grain legumes, pigeon peas are deep-rooted, drought-tolerant, and free from consistently and devastatingly harmful diseases. Early growth is slow. This fact may account for the practice of planting pigeon peas in mixtures with cereals which grow rapidly, are harvested, and leave the pigeon peas to grow and mature afterwards. They are susceptible to a range of foliage-damaging insects, pod borers, and nematodes, although the damage may be less severe than with other crops. Under storage, pigeon pea seed is extremely susceptible to attack by bruchid insects.

Beans

The dry bean (*Phaseolus vulgaris*)–common bean, snap bean, kidney bean, haricot bean–is a principal protein source in the eastern part of Zaire, in Rwanda, Burundi and especially Uganda. It is grown in other high-altitude areas of eastern Africa and Ethiopia and, as a winter crop, in Sudan. In Tanzania and Malawi, seed crops are grown for export.

Annual production of *P. vulgaris* in Africa is about 800,000 metric tons (about 7.5 percent of the world total) on about 1.3 million hectares comprising about 5.5 percent of the worldwide area. Average yields around the world are 470 kg/ha; in Africa the average is 600 kg/ha. Under modern farming methods in the United States, yields average more than 1.5 tons/ha; experimental yields of up to 4 tons/ha have been achieved in Asia and the United States. As is the case with other grain legumes, yields are low because the varieties used have small inherent potential and are susceptible to a wide range of diseases and pests and the production and management practices are unsatisfactory.

Phaseolus beans are inferior nutritionally to cowpeas and pigeon peas. They contain about 22 percent protein, with large percentages of lysine and threonine and low sulfur amino acid content. They contain many factors limiting digestibility–antimetabolites, hemagglutinins, trypsin inhibitors, and flatus-producing factors.

Little work has been done on breeding improved varieties of beans outside the United States and Europe, and most bean programs have emphasized specific problems, such as resistance to insects and diseases, important only in limited areas. Varieties produced in this way have a narrow genetic base and, therefore, are not outstandingly superior.

Phaseolus beans are susceptible to more than 20 fungal and bacterial diseases and viruses. More than half the crop may be lost to insects that attack the plants in the field and the seed in storage.

RESEARCH NEEDS

The primary goal of research in the grain legumes must be to enable peasant farmers, to whom these crops are most important, to obtain consistently good yields. Meeting this goal requires not only attention to developing cultivars with large yield potential and to improving methods of raising them, but also attention to breeding for resistance to pests and diseases as well.

Also urgently needed are forms adapted to different environments, especially the humid tropics. Though the present distribution may foster valuable trade when the drier legume-growing region and the wetter protein-short region adjoin each other, large areas of the humid tropics where people need better diets lie beyond the reach of such exchanges.

Since the different grain legumes share many common features of structure and variability, there will be great advantages in organizing future work on them so that workers on different species and genera will be able to exchange ideas and results as they go along. An African grain legume newsletter could be extremely helpful.

RESEARCH CAPABILITIES

Cowpeas

Three countries in Africa–Nigeria, Senegal and Uganda–support programs of research on cowpeas. In Nigeria this research takes place at Ahmadu Bello University, Zaria; at the Moor Plantation (collection of germ plasm and breeding studies); the University of Ibadan, and IITA, Ibadan; and at the University of Ife (inheritance studies and screening for disease resistance). In Senegal research is concentrated at the Centre National de Recherches Agronomiques, Bambey (breeding and varietal trials for yield, earliness, photo-insensitivity, and upright plant habit); in Uganda, Makerere University, Kampala, has a program on varietal trials and pest resistance studies.

Present research efforts on cowpeas in Africa should be linked together, and based at a main center where research on agricultural systems is strong, because of the need for greater understanding of the role cowpeas may play within different farming systems. IITA is a logical choice for this effort with closely linked collaborative investigations at Samaru and Kano in Northern Nigeria and at Bambey, Senegal. IITA scientists started work on cowpeas in 1970 and by 1972 had 35 acres (14.2 ha) of breeding material, 15 acres (6.1 ha) in plant protection experiments and 15 acres in physiological and agronomic studies. If a corresponding program on pigeon peas is established at IITA, the combination of overall capabilities will be especially attractive.

Pigeon Peas

Research needed on the highly promising pigeon pea could logically be based on the comprehensive central collections being gathered at Makerere University. Started in 1969, research there has so far concentrated on breeding improved varieties obtained through screening the germ plasm collection of the Indian Agricultural Research Institute.

Since there are remarkably few apparent barriers to great improvements in yields of this nutritious crop, exploratory research programs should be encouraged. A research program has been started at IITA, associated with the cowpea research there as has been suggested above, and in close cooperation with ICRISAT in India.

Beans

Makerere University in Uganda and Cambridge University in the United Kingdom, with support from ODA, have recently undertaken a collaborative research effort on *Phaseolus* beans in Africa. Using materials collected by The Rockefeller Foundation in part, this program is presently concentrating on breeding for disease resistance. It may well be appropriate during the next few years to associate other research on the common bean in Africa as closely as possible with this program and to take other species of *Phaseolus*, particularly the lima bean (*P. lunatus*) into consideration.

In the Malagasy Republic, a research program on *P. lunatus* has been under way for some years. Work on *P. lunatus* is also being conducted at IITA, which is surveying the potential of a number of miscellaneous bean varieties.

CONCLUSIONS AND RECOMMENDATIONS

The food legumes have exceptional immediate potential for alleviating human malnutrition in tropical Africa by virtue of (1) their ability to grow vigorously under a wide range of environments and on poor soils without supplemental nitrogen; (2) the potentially short maturity time of certain varieties, particularly of cowpeas and dry beans; and (3) the extended fruiting periods of long-duration viny species and woody perennials. In addition, they provide the only nonprocessed, storable, and transportable protein food concentrate for both rural and urban use. Excellent in nutritional value, they complement the diet of the humid tropical zone based on roots, tubers and plantains, and fit admirably in the complex peasant farming systems.

The Committee subscribes to the suggestions submitted to the United Nations Protein Advisory Group symposium on nutritional improvement of food legumes by breeding (PAG, 1971)–namely, that the most efficient vehicle for achieving results in upgrading food legumes comparable to the success of the Green Revolution in cereal improvement would be a series of international technical networks of national research programs cooperating with international and regional institutions and other international and national agencies.

- *The Committee recommends that one or more national centers be designated in each of the different ecological zones where knowledge and resources could be pooled to catalyze research and training activi-*

ties; such programs should be accorded high priority for support from CGIAR and interested donor agencies. For Africa this will entail

1. expanding experiment station facilities at the national level;
2. enlarging training programs in national faculties of agriculture and at such institutions as IITA for agricultural specialists, particularly pathologists and entomologists;
3. enlarging collections of germ plasm and using wild species in breeding programs for obtaining increased yield, better nutritional composition and resistance to pests and diseases;
4. improving communication between researchers in different countries through seminars and through the publication of a newsletter;
5. tightening cooperating relationships with institutions outside Africa—such as ICRISAT, Hyderabad, India, and CIAT, Cali, Colombia—which have research programs on grain legumes; and
6. including research on production systems in which food legumes can also contribute nitrogen and protect soil against erosion, thereby improving the yields of other crops grown in association with them or subsequently.

• *Among the food legumes—cowpeas, pigeon peas and the common bean—the Committee recommends according top priority to cowpeas in African research, particularly to increasing yields and controlling pests and diseases.* Knowledge of the association of this crop in mixtures with sorghum or maize could lead to improved means of soil management, especially of the nitrogen cycle. With regard to pigeon peas, the ongoing research, collecting and testing of a wide variety of types should be continued and amplified. Such research as is being conducted in Africa on the common bean ought to be well integrated with the research under way on that crop at CIAT; low yields due primarily to root rot and other plant diseases would be a prime target for research effort. The potentials of less familiar species like the lima bean, winged bean rice bean, yam bean, jack bean and "asian grams" should be explored.

VI

Roots, Tubers and Plantains

The roots, tubers (including the "Irish" potato), and plantains constitute an illogical conglomerate of distantly related plant species; nevertheless, they belong together in this discussion of basic food crops because they furnish calories for people who live where the cereal crops do not flourish–primarily, but not exclusively, the humid tropics. Cassava (Figure 7) and, to a lesser extent, yam, cocoyam and sweet potato, are grown extensively over the continent. The Irish potato is a cool weather or high altitude crop for which there is increasing demand from many city dwellers. The plantains have a wide range and are of major importance as a secondary staple over much of the forest belt.

CASSAVA, YAM, COCOYAM AND SWEET POTATO

Current Status of Production and Research

Cassava, cocoyams, sweet potatoes and possibly yams are capable of producing more food calories in a given area than any other lowland crop. About 50 million tons of these roots and tubers are produced annually in tropical Africa, where they are preferred staples. They generally are produced more cheaply and with less labor and attention than cereals. They can adapt to diverse climatic conditions, and they suffer

FIGURE 7 Cassava. (Photo courtesy of Dr. Edward S. Ayensu, Smithsonian Institution, Washington, D.C.)

from fewer diseases and insect pests than the cereals–although the effects of the diseases and insects which do attack them can be very severe.

In addition to their value as human food, these crops can be used as livestock feed and for industrial products such as starch and alcohol. Dried cassava chips exported from Kenya, Ghana, Thailand and countries of South America are becoming an important source of carbohydrates in livestock feeds. If cassava can be produced more cheaply for this use and for human consumption as well, it may be able to compete successfully in international markets with the feed grains.

Cassava is the most widely grown and most drought-resistant of the root and tuber crops. Its leaves provide food as well as its roots. The poor quality and small amounts of protein in the roots and high cyanide levels are important liabilities, and cassava research has been directed toward them. The one species of the genus that is grown for food, *Manihot esculenta,* has only 1.6 percent protein in its roots on a dry weight basis, but the plant breeders at CIAT in Colombia have discovered varieties of this species with a much higher percent. Plant breeders have also been attempting to breed cassava plants that contain lower levels of cyanide.

Yams (Figure 8), which have a high potential for food production, are somewhat preferred in West Africa. In general the yams indigenous to Africa contain more protein than cassava, ranging from 4 to 7 percent on a dry weight basis, but one introduced species (*Dioscorea alata*) has been found to contain 12 percent.

In East Africa, and some parts of West Africa, sweet potatoes (*Ipomoea batatas*) are preferred to yams as a food crop. They fit well into multiple cropping systems, have limited susceptibility to insect pests and diseases, and are tolerant of drought. They yield poorly in some parts of Africa, however, and are difficult to store.

Cocoyams, the common name applied to *Colocasia esculenta* from Asia (also called "old cocoyam" or "taro") and *Xanthosoma saggitifolium* from the New World, are referred to as "macabo" in francophone West Africa. Cocoyams are widely grown in the "yam zone" of West Africa in small plantings for local consumption. Medical evidence presented in the 1930's, which may or may not have foundation in fact, indicated that, where cocoyams are a major part of the diet, the people are subject to nephritis. As a protein source, however, they are superior to cassava. Biochemical assays indicate that cocoyams contain about 7 percent protein on a dry weight basis (U.S. Department HEW and FAO,

FIGURE 8 Yams on sale in market in Accra, Ghana. (Photo courtesy of Dr. Edward S. Ayensu, Smithsonian Institution, Washington, D.C.)

1968). Some researchers would question the significance of such comparisons because of the low protein content of all the tuberous plants.

Research Needs

The research needs of the root crops follow the pattern of needs of the cereals and the grain legumes but are many times magnified because so little research has been done on these crops in years past. All of the root crops might benefit from redesign of their plant types, thereby enabling them to profit from nitrogen fertilization and from other intensive farming practices.

The overwhelming priority for research centers is on cassava. Here, diametrically opposed objectives offer scientists great scope; first, to upgrade this plant for human and livestock consumption by improving its nutritional qualities and, second, to mold the plant for industrial purposes by exploiting such nonnutritional qualities as large starch grains and low cellulose, fat and protein content. Other outstanding challenges are to develop mosaic and bacterial wilt resistant varieties; to encourage the broader use for food of cassava leaves, which contain up to 30 percent protein on a dry weight basis; to study cassava production and its effect on farm income; to study cassava marketing and processing techniques–those, for example, that will advance the use of cassava flour in bread where wheat shortages prevail.

Yams will need research not only to improve yields, but also to extend the harvesting season, and to reduce manpower requirements for production. Smaller tubers uniform in size allowing for mechanical harvesting, with reduced perishability and a longer storage life once they have been taken from the ground, must be developed and produced at lower manpower requirements if yams are to hold their own in competition with cassava.

Research on sweet potatoes ought to exploit yellow varieties, which have a relatively high vitamin A content.

Research Capabilities

In Nigeria, investigations on cassava have been under way at five locations. The Federal Ministry of Agriculture has had a comprehensive program at Moor Plantation in Ibadan dealing with plant populations, dates of planting, disease control, processing and storage, and breeding of mosaic-resistant varieties. The national cassava collection, formerly maintained at Umuahia, then at Moor Plantation, Ibadan, is again being assembled at Umuahia. Similar research has been under way at the

Western State experiment station also located in Ibadan; at the Midwestern State Research Division of the Ministry of Agriculture in Benin City; at the University of Ife; at the Crop Research Station of the Ministry of Agriculture in Agege, near Lagos; and at the Nigerian Stored Products Research Institute. Cassava, yam and other root crop research is to be centered at Umadike in the East Central State and substations will be maintained elsewhere. In the Malagasy Republic, the Institut de Recherches Agronomiques Tropicales et des Cultures Vivrières (IRAT) is the center for research on the cassava.

Yams are under study at the same stations and also at the Institute of Agricultural Research (IAR) of Ahmadu Bello University in northern Nigeria and at the University of Ibadan. For several years, a research program on mechanized cultivation of yams has been undertaken in Ivory Coast.

Sweet potatoes are under study primarily at Moor Plantation and at the Benin City station in Nigeria, with emphasis on plant breeding and entomology. A program on cocoyam and macabo is also being carried out in Cameroon.

IITA in Ibadan is engaged in a root and tuber program that forms an integral part of its mandate to conduct research on the basic food crops of the humid tropics. The program emphasizes the collection and evaluation of existing cultivars, including wild varieties, from all parts of the world. The selection program stresses plant types suited to intensive, mechanized cultivation; resistance to diseases, nematodes and insects; improvement of quality and nutritive value for human consumption; yield; keeping quality; and wide adaptability. The economists and crop specialists at this institute cooperate with their counterparts at CIAT in Latin America and with the research workers of the national experiment stations of the countries of Africa in order to assist in strengthening the research programs at those important centers as well.

POTATO

Current Status of Production and Research

The Irish potato (*Solanum tuberosum*) is growing in importance in Africa, and a potato-growing industry is developing around several of the metropolitan centers, notably Kano and Jos in Nigeria, Nairobi in Kenya, and to a lesser extent Entebbe and Kampala in Uganda and Addis Ababa in Ethiopia.

The potential for growing the potato in climates warmer than those in which it now thrives is considerable. The potato-breeding experts of the Centro International de la Papa [International Potato Center (CIP)], with headquarters in Lima, Peru, are attempting to increase its tolerance to high temperatures. If the tolerance of the potato to warm temperatures can be raised as much as 1–1.5 °C (2–3 °F), vast areas of Africa will be open to production of the crop. Since it is a short-season crop, with only 3 months from planting to maturity, the potato will compete well with cassava and other tuberous crops that require 12–18 months from planting to maturity.

Research Needs

Solutions are needed to two major disease problems affecting the potato in Africa: bacterial wilt (*Pseudomonas solanacearum*) and late blight (*Phytophthora infestans*).

Virus diseases are also damaging, but the African continent does possess highland niches suitable for producing potato seed free of virus and other diseases. Seed so grown can then be planted at low altitudes and, for the short space of one season, escape serious damage even though the lowland area may harbor both the viruses and their vectors. Capitalizing on their own environmental resources, some African governments can at least obviate the need for importing from northern Europe and elsewhere costly seed certified to be free of virus and other diseases.

Research Capabilities

An IAR unit based at Jos, Nigeria, is seeking to breed a potato resistant to bacterial wilt and to late blight. It is cooperating closely with major American centers—United States Department of Agriculture in Beltsville, Maryland, University of Wisconsin in Madison and CIP in Lima, Peru—which provide breeding material for testing at Jos. In August 1971 the National Agricultural Development Seminar in Ibadan called for intensification of this program.

An attempt is being made in Cameroon to adapt to local conditions the findings obtained elsewhere on varieties, cultivation techniques and mineral nutrition.

The College of Agriculture, Haile Selassie I University, has a long-term variety trial and disease resistance investigation program at its campus at Alemaya, Ethiopia. Potatoes are grown extensively as a year-round cash crop by farmers in the area both for local consumption, particularly during fasting periods, and for export to Djibouti.

The government of Kenya has already engaged a research team of potato specialists from the United Kingdom to assist in developing an industry producing seed that is certified to be free of virus and other diseases. However, capabilities for exploratory research, particularly concerning the production of certified seed in East Africa, need expansion. Projects in Africa can, with advantage, grow in step with the international potato research programs in other parts of the world.

PLANTAINS

Present Status of Production and Research

The cultivated plants of the genus *Musa*, which include the starchy plantain and the sweet-fleshed banana as well as Manila hemp (*M. textilis*), apparently were first domesticated in Southeast Asia long before the Christian era. They came into eastern Africa at least 2,000 years ago through a highly developed trade around and across the Indian Ocean, which in ancient times distributed taro, sugarcane, citrus, rice and other East Asian plants widely in the Old World.

Plantains are grown today in all parts of tropical Africa and as the main staple in Uganda, which produces more than any other country. They are of major importance to the people in Rwanda and Burundi, in Bukoba, Tanzania, in the northern parts of the Congo Basin; and to the Ashanti people in Ghana. Here they are not a fruit but a carbohydrate producer and, as such, present the same protein deficiency problems as cassava, yams, sweet potatoes and cocoyams. They compete with the starchy roots but have a different husbandry. They are cooked in a variety of ways and are fermented into beer. The traditional husbandry, practiced in permanent fields, maintains groundcover and hence tends to restrict erosion.

Norman W. Simmonds (Baker and Simmonds, 1951, 1952) made a continent-wide reconnaissance of plaintains in 1948. Little is known, however, of variation in *Musa* in Africa as a whole. Neither is there much information on the prospects for introducing improved types. Institut Français de Recherches Fruitières (IFAC) has, however, assembled plantain collections at Nyombé station in Cameroon and at Azaguié in Ivory Coast and has conducted culture trials at these locations. In years past the Yangambi Research Station in Zaire led in plantain research; many of the cultivars are still there.

Research Needs

The first question facing researchers in plantains is to determine the range of areas in which the crop could usefully be encouraged as a valuable and cheaply produced energy source. A pan-African survey of the factors limiting production of the crop and of potential areas for its cultivation would be valuable. National programs to expand the crop in the wetter regions where dietary calories are insufficient, as in eastern Nigeria and in Zaire, could develop from this survey.

As for germ plasm, modern tissue culture methods should be used to assemble a large disease-free collection. Studies of variation in protein content and quality would also be of value to breeders.

Contrary to the opinion generally expressed, it is important to undertake agronomic studies (effects of soil, variety, nutrition and protection practices) on the plantain. These will lead to quicker improvement of plantain than will hybridization studies. The collection and comparison of sets of cultivars is of primary importance. It is possible to use plantain as a feed for pigs and cattle, as some African people already do, and in time it may be grown in places solely for this purpose.

Banana diseases and pests other than nematodes do not appear to be of great importance in Africa at present, but a continental survey of plantain diseases, pests and control practices–in the field and from the literature–is needed. Nematodes seem to affect yields, and the first step is to find out how; then whether there are resistant forms of plantain, and what nematode control measures are possible at what cost.

Research Capabilities

One of the first efforts toward building capabilities, virtually nonexistent at present, for plantain improvement would be to establish centers where varieties could be assembled and evaluated. Staff members at Makerere University in Uganda have initiated field experiments on the "matoke" banana to ascertain nematode populations in the soil as they influence yield, and water and fertilization needs of that particular plantain. This research, taking place within a faculty of agriculture, will expose students to the needs and opportunity for research on this important commodity.

ENSETE

The false banana of the species *ensete* is grown fairly widely in Ethiopia as a starchy staple; the stem of the plant is fermented in underground pits, then consumed. The College of Agriculture at HSIU has a research project on Ensete at its experiment station at Debre Zeit.

CONCLUSIONS AND RECOMMENDATIONS

- *The Committee recommends strengthening research on cassava, sweet potatoes, yams and cocoyams in the order listed because these* *crops thrive in those parts of the humid tropics where the cereals do poorly and where the need for improving the quality of the staples that feed the people is the greatest.* Long neglected from a research standpoint, they offer great opportunity for improvements in quality, yield and marketability. Potential income-producers for the grower, the roots, tubers and leaves of these crops can serve as livestock feed, thus helping make available more animal protein. Plantains merit investigation for similar reasons.

Methods for enhancing the research capabilities directed toward upgrading roots, tubers and plantains correspond to those set forth for the cereals and the grain legumes–notably, offering students training and research opportunities on these crops in the national faculties of agriculture, introducing new programs of research or revitalizing existing ones at the national experiment stations of the humid tropics especially, and building international facilities that encompass wide geographical zones where the problems of root crop and tuber production are common–centers that can also help relate the research programs of Africa to those of other parts of the world.

Cassava, the most wide-ranging of the root crops, is a native of South America where the wealth of its germ plasm lies. Research on this crop needs primarily to be one of plant breeding to produce plants of improved protein quality, high yield, and resistance to mosaic. It will be necessary to develop linkages with the CIAT program in Colombia and with other Latin American centers of cassava research, although the virus disease, cassava mosaic, does not occur in Latin America and the Latin American stock has not developed resistance to it.

Yams indigenous to Africa have already been investigated at experimental stations in Nigeria and at other national experimental stations of West Africa. Research should be fostered not only in breeding yams of high quality and good yield, but also for the production and harvesting of tubers by mechanized operations, thereby reducing labor costs.

Sweet potato research has been concentrated in East Africa, where this plant flowers more readily than in other parts of the continent and can therefore be crossed most easily. Other centers of research are developing in Africa, notably IITA at Ibadan where flowering also presents little problem when the sweet potatoes are planted during the cool season of the year. Research at Makerere University in Uganda should be intensified on this crop.

Plantain research has recently begun at the Faculty of Agriculture at Makerere University in Uganda and should be expanded at that locality.

The Irish potato is gaining popularity in Africa, where people will demand that its range of productivity be extended to warm climes while the cool, isolated areas of the highlands can serve for growing disease-free seed.

• *The Committee recommends that research on the Irish potato, a native of Latin America, be keyed into the program of the international center for potato research in Lima, Peru, with important applied studies to take place in Africa–northern Nigeria, Cameroon, Guinea (the Fouta Djallon region), and the highlands of Kenya and Uganda primarily.*

VII

Vegetables, Fruits and Nuts

The vegetables (tomatoes, onions, peppers and local vegetables), fruits (the "sweet" banana, pineapples, citrus fruits, avocado pears, mangos and guavas), and nuts (cashew and macadamia) will help diversify both agriculture and diets throughout Africa. They serve as an important source of vitamins and minerals to local populations, particularly in the growing urban areas. Some are already cash crops for export to Europe and America as well as within Africa.

The tendency too often in the past was to plant vegetables, fruits and nuts at botanical gardens but not to disseminate them widely into the research centers or experiment stations nor to investigate their potential contribution to a varied agriculture in the African countries. Several stations have nevertheless developed research capabilities on horticultural crops; research on the banana and pineapple has been in progress for more than 20 years at a specialized IFAC (Institut Français de Recherches Fruitières Outre-Mer) research station in the Ivory Coast.

PRESENT STATUS OF PRODUCTION AND RESEARCH

Vegetables

The tomato (*Lycopersicon esculentum*) in particular has become an important item in the African diet, especially in West Africa. Vast quantities of tomato paste are imported. In 1967, Italy alone exported over

18,000 metric tons of tomato paste to West Africa. Many small farmers are beginning to grow tomatoes on a commercial scale in the environs of metropolitan areas such as Kano, in northern Nigeria. Commercial companies, notably the Cadbury concern, are beginning to process tomatoes to make a locally acceptable tomato paste. Research on tomatoes is in progress in Nigeria, Ghana, Senegal, Ethiopia and Upper Volta. Yields of 50 tons/ha have been achieved in Nigeria with selected varieties grown under irrigation.

The onion (*Allium cepa*) is another popular vegetable. According to recent estimates, Nigeria alone consumes 375,000 tons per year. It is an important export crop within Africa; for instance, 70 percent of Niger's annual crop of 38,000 tons is exported southward.

Peppers (*Capsicum frutescens; C. annuum*) are almost as important as onions and tomatoes. An interesting development is the cultivation of peppers in Ethiopia for export to the United States for use both as condiments and as a source of natural coloring additive to tomato products such as ketchup.

Aside from these crops known everywhere, many local vegetables are important in Africa. A survey of vegetable consumption in several villages in the neighborhood of Sokoto, Nigeria, showed that, although the farmers grew western types of vegetables for sale in the town, they ate only local vegetables such as leaves of the baobab tree (*Adansonia digitata*) in Figure 9, okra (*Hibiscus esculentus*), sorrel (*Hibiscus sabdariffa*), *Amaranthus* leaves, karkashi (*Ceratotheca sesamoides*) and melon seeds.

A limited winter exportation to Europe and other parts of Africa has been noted since 1969 for such vegetables as snap beans and eggplants. This trend of exportation has been mainly from Senegal with some exports also from the Ivory Coast, Upper Volta and Niger.

On tomato, a considerable amount of research remains to be done, including control of tomato pests, especially nematodes, and diseases that attack it during its growing period; development of tolerant varieties; development of cultural practices to produce the highest yields in various regions; and removal of the barriers to more widespread production, particularly in transportation and marketing. On onions, much more research is also necessary—to develop better storage and processing techniques. On the local vegetables, a much more concentrated research effort is required to establish their potential.

Fruits

Many types of fruit tree presently cultivated in tropical and equatorial Africa were introduced from Asia or America. The arrival of some, like

FIGURE 9 Baobab tree.

the date palm, goes back to ancient times. Others came more recently from chance commercial contacts and from the work of explorers and botanists at the end of the nineteenth century and the beginning of the twentieth. These workers created magnificent testing gardens some of which still exist at Conakry, Guinea; Entebbe, Uganda; Brazzaville, Republic of the Congo; and other locations. These gardens contained a wealth of diversified species, but their resources were not properly exploited until World War II.

The cultivation of strawberries on a commercial scale in the highlands of East and Central Africa is a recent development which has been encouraged by the increasing air freight traffic between these parts of Africa, northern Europe and other countries. Strawberries are also cultivated on a commercial scale at sea level in the Cape Vert of Senegal during the winter season.

Francophone Africa has experienced a spectacular increase in exports of tropical fruits over the past 20 years. Banana production has doubled. Pineapple production rose from none to an annual level of 120,000 tons of fruit processed for canning and 20,000 tons of fresh fruit for export, and prospects for the years ahead exceed 200,000 tons of processed fruit and 40,000 tons of fresh fruit. Many factors have contributed to the rise in production, but research has been one of the most important.

However, some of francophone Africa has special problems in fruit cultivation. In Niger, for example, fruit production is limited to the date palm, the guava tree and some orchards or gardens of mango and citrus fruit. Here the researchers have mobilized all resources in the area for a practical purpose—to define the type of orchard that could be operational and profitable most quickly. A 4-year IFAC mission undertook this assignment in 1967.

The strategy of research in fruit production in francophone Africa has developed around the definition of the right fruit for the right region according to climatic and socioeconomic conditions. This strategy includes three tactics: exploiting and improving existing fruit crop resources; creating new intensive groves of fruit trees; and investigating new species that may be adapted to African conditions.

The first tactic involved improving production of the orange for oil used in perfumes in Mali and Dahomey. There, wild orange groves exist far from large market centers. In west-central Cameroon, it led to investigations of the avocado and attempts to exploit the wild fruit groves there. In Mauritania, it called for obtaining international collaboration to combat the cochineal scale insect, which is seriously weakening the date palm groves.

The second tactic included collecting information on environmental conditions, microclimates, and the like, for certain species in preparation for large-scale planting of fruit trees under irrigation. Fruit trees have been planted in oases, which substitute for the wind screen in managing the environment to suit the fruit trees. Shade is provided during the sunniest hours of the day and the circulation of hot air currents, which cause excessive evaporation and transpiration and thus destroy blossoms, is checked.

The third component tactic of the strategy constituted research into production of new types of fruits and has called for periodic scientific forays into other fruit-growing areas of the world–the Americas, for example–and has resulted in large primary collections of new species for distribution and trial throughout Africa.

There is a general trend toward pineapple cultivation in anglophone areas as well as in francophone countries. This trend will require an expansion of research. In Swaziland, Tanzania, Uganda and Kenya the pineapple stands a good chance of becoming a widely planted cash crop that will help diversify agriculture. Commercial concerns that want to promote pineapple production ought to do the exploratory testing of varieties, but government research stations should be cooperating to identify locations where pineapples will grow best and assisting with the early adjustment of the crop to local conditions.

Banana In the banana-growing zone of francophone Africa, IFAC has attempted to define the conditions of cultivation, especially soil fertility and insolation, that will lead to maximum production. The mineral nutrient requirements of this crop in Africa are now quite well-known. The influence of potassium on the synthesis of sugars and amino acids, as well as its effects on the general metabolism of the plant, has also been studied.

Current research on the banana deals with the effects of climate on the plant, the causes of physiological anomalies like yellow pulp in Cameroon, and the factors that produce flushes of growth and growth stoppages. Studies of the effect of transpiration on mineral nutrition and sugar metabolism and studies of the effects of cultivation in different types of soil and *in vitro* on root system biology are being pursued by agronomists and soil scientists in collaboration with pathologists and nematologists.

Banana production in Africa is most frequently limited by rooting deficiencies. Deterioration of the soil structure or excessive water in the soil leads to soil clogging, resulting in feeble root growth and a small yield. Leaching caused by heavy tropical rains reduces the effectiveness of mineral fertilizer.

Substantial advances have been made in protecting the banana plant against diseases and pests. The Cameroon banana industry has been among the first to use a systemic fungicide of the benzimidazole type to control one of its serious fungus diseases, *Cercospora* leaf spot—a method perfected by IFAC workers. This step made it possible to reduce the number of land and air spray treatments necessary. Work on the banana stem borer (*Cosmopolites sordidus*) and on nematodes has brought these pests under control. Nematological studies have resulted in the development of efficient treatments with new compounds, now used particularly in Ivory Coast and Cameroon.

In post-harvest technology, the study of banana packaging and transport has almost completely eliminated spoilage during shipment and marketing.

Pineapple A wealth of information on the pineapple has accumulated from research in Hawaii and Puerto Rico, but these findings cannot be applied without further testing in the pineapple-growing areas of Africa. Whether for canning or fresh fruit exports, pineapple cultivation requires precision, and the research applied to it is sharply location-specific.

Research on pineapples has covered the following topics: the nature and properties of African soils; the technology of production, as it relates to the organization and mechanization of plantations and to existing socioeconomic conditions; the scheduling of flowering so that the fruit matures at predetermined times; mineral nutrition; and the protection of the crop from *Phytophthora* fungus disease, from insects and from nematodes. Progress has also been achieved in processing the fruit by setting up calibrator-equipped packaging stations and by cardboard packaging for export.

Citrus The demand for new plantations of citrus is widespread and will grow with increasing urbanization. Improved modern varieties adapted to the subtropical climates of Africa are therefore needed.

For years, various diseases of paramount importance wherever citrus is grown have dominated citrus fruit research and development. They still do. International organizations can play a crucial role in disease prevention by channeling materials and research information gained elsewhere to the growing citrus research centers of Africa. The International Organization of Citrus Virologists and IFAC have collaborated in a review of citrus fruit stocks free of disease. They have tested a considerable number of strains and produced grafts from these stocks free of known viruses for renovating the material in the nurseries and multiplication plots in Africa.

The attempts to introduce better stock to Africa are aimed at local consumption of fruit; but—in spite of efforts to produce fruit juices, powders and frozen products—the production of fruit essences for export is still important in Africa today. Existing plant stocks and the special climatic conditions, notably in Mali, encourage this type of citrus culture.

Other Tropical Fruits Fruit research efforts through IFAC and its associated government experiment stations are not limited to the banana, pineapple and citrus. Surveys and tests on the almost inexhaustible range of tropical fruits that can be grown in Africa—avocado, papaya, guava, grenadine, date, mangos, mangosteen, etc.—are also being conducted. Many of these fruits are already being grown, but in a casual rather than a serious way.

Nuts The cashew nut (*Anacardium occidentale*), which the Portuguese brought from South and Central America to East Africa as early as the fifteenth century, became well-established and today constitutes an important export commodity in the agricultural economies of Mozambique, Tanzania and the Malagasy Republic. Over the centuries, however, this crop seems to have been poorly researched (although, recently, investigations undertaken at the Eetangirika Research Station in the Malagasy Republic under IFAC incentive did lead to reclamation of a 1000-hectare grove of trees and then to planting of 20,000 new hectares). Some technological research has also been under way with a view toward building a modern processing factory to devise efficient machinery for shelling the cashew. The Cocoa Research Institute of Nigeria now has a cashew improvement program under way.

RESEARCH CAPABILITIES

The stations developing research capabilities on vegetable crops include the University Experiment Station at Legon, Ghana; The Institute for Agricultural Research at Samaru in northern Nigeria; IRAT stations at Farakoba, Upper Volta, and Tarna, Niger; Scott Laboratories on the outskirts of Nairobi, Kenya; and Kabanyolo Farm of the Faculty of Agriculture, Makerere University, Uganda. A major research effort on onions is under way in Ethiopia. The International Institute of Tropical Agriculture has initiated work with tomatoes, peppers, melons and certain leafy vegetables.

Probably the most efficient and inexpensive way of improving vegetable crop research capabilities is to make sure that agricultural students interested in vegetable crops can take courses and undertake research with a long-term commitment to working on a specific vegetable. At the same time existing experiment stations, especially those that are fairly close to urban centers, could easily broaden their vegetable research effort.

Research on fruits in francophone Africa is quite well-developed IFAC program has three major objectives: export growth, increasing internal consumption of fruits, and improving nutrition and technol- similar organization exists for fruit research in anglophone Africa. The IFAC program has three major objectives: export growth, increased local consumption of fruits, and improved nutrition and technology. In developing fruit cultivation for export, an increasing number of villagers have been able to become producers. A long-term IFAC goal is to widen the range of exportable products, whether fresh or processed. Emphasis is placed on raising vitamin consumption—low in those populations of Africa where fruit never exceeds 10 kg per capita per year—and on production of high-grade fruit for the urban market. Lowering costs of production is important in terms of the purchasing power of most consumers in Africa. IFAC experimental laboratories and installations handle four major disciplines in research: agronomy and soil science, plant physiology, plant protection, and insect control. The researchers manning these disciplines collaborate closely with the researchers at Office de la Recherche Scientifique et Technique Outre-Mer (ORSTOM).

CONCLUSIONS AND RECOMMENDATIONS

Few commodities illustrate as do the vegetables and fruits the importance to agriculture of an adequate infrastructure—roads, railways and airstrips; marketing facilities; and processing plants—or the beneficial effect that the growth of urban centers has on agricultural development in the hinterland. Intensive farming of vegetables and fruits near urban centers functions as a service industry providing people in the cities with supplementary quantities of vitamins and minerals that, were they living in the country, they might obtain from incidental crops close at hand. The perishable nature of the vegetables and fruits requires investigations to improve transportation, marketing and processing, as well as the cultural practices, the varieties best adapted to the region in which these crops are grown, and plant disease and insect control.

- To foster production and consumption of vegetables, fruits and nuts and for the general importance to agriculture of transportation, marketing and processing, *the Committee recommends research appropriate to the improvement of the transportation, marketing, and processing infrastructure of the agricultural sectors of the economies of the African countries.*
- Industry normally should be able to bear the cost of the main research on intensively planted, high-value crops, such as fruits and vegetables. However, *the Committee recommends that governments participate in and/or monitor research on the fruits and vegetables in order to ensure constant upgrading of the vitamin and mineral content of these crops to improve their nutritional quality to the consumers.*

Here, too, faculties of agriculture have a responsibility to open up training and employment opportunities to young agriculturists who wish to become specialists on a particular vegetable, fruit or nut.

VIII

Sugarcane

CURRENT STATUS OF PRODUCTION

Sugar is a popular item in the diets of many people (in addition to its wide industrial use) and consumption tends to rise as incomes improve. Indeed, the Indicative World Plan (IWP) predicts a more rapid rate of increase (3.3 percent per annum) in the demand for sugar in Africa than for cereals, roots or legumes (FAO, 1969a). The value of sugar production in East Africa in 1964–1966 was $96.7 million, according to the Economic Commission for Africa (ECA)–greater than that of rice, cassava, oilseeds or sisal.

In many African countries sugar is an important commodity for its export potential. Sugar imports into West Africa are currently estimated at about 300,000 tons annually. Because of the demand on foreign exchange imposed by such a high level of sugar imports, it is becoming attractive to many countries as an import substitution crop.

Raw sugarcane production in the IWP region of Africa south of the Sahara was estimated to be about 5.6 million metric tons in 1966–1967; the rest of Africa (including South Africa, Mauritius, Rhodesia and the Portuguese territories) produced 29 million metric tons, and the world, 514 million metric tons.

Overall consumption of sugar in the IWP countries rose from 4.7 to 7.2

kg per capita per annum between 1951 and 1963, and is still rising steadily. In Mauritius, with a large sugar surplus, annual consumption is stable at about 40 kg per capita. In contrast, annual consumption of sugar in Central Africa and West Africa is very low; in 1965, per capita consumption was estimated at 1.3 and 5.8 kg for Nigeria and Ghana, respectively. Cane production, 1966–1967, was at moderate yields, averaging 56.4 tons/ha from only about 80,000 hectares, intensively managed. About 85 percent of this area was in East Africa.

Almost all African countries have good potential to produce sugar for the domestic market, under irrigation or otherwise (Rene F. E. Devred, FAO, 1972, unpublished data). Those countries other than Mauritius with surpluses at present—the Malagasy Republic, Congo (Brazzaville) and Uganda—export sugar mainly to other African countries; Uganda exports mainly to Kenya and the others to countries under the Organisation Commune Africaine et Malgache (OCAM) agreement. The April 1971 ECA/FAO report on East Africa (ECA/FAO, 1971) reviews the possibilities for African intraregional trade in sugar. Although there is a large sugar deficit in West Africa now, sugar faces an uncertain market over the long range, since most countries are taking steps toward becoming self-sufficient in this commodity. The mid-term prospect, therefore, is that each country will develop its own sugar industry; it is to this situation that research work must be addressed.

Though the world market price for sugar is now fairly good, any attempt to export sugar from a developing country on to the world market can succeed only if the production system is very efficient. Even if the main purpose of promoting sugar production is import substitution, production costs must be kept low to make the exercise attractive. Efficiency in the processing of sugar depends critically on a well-managed, continuous flow of cane to the mill. Moreover, sugar is a long-term crop, taking 12 months or more to mature, and irrigation is usually essential. These requirements suggest that production must be based on a plantation system, even if cane is also accepted at the mill from nearby small-scale growers. In fact, most of the sugar produced and distributed in Africa at present comes from intensively cultivated plantations. It seems reasonable to expect that future development will also be on a plantation system, which need not be excessively mechanized, and can therefore provide a large number of jobs per hectare.

RESEARCH NEEDS

The research requirements are those of a relatively sophisticated form of farming with reasonably skilled management. Much is known about suitable agronomic and irrigation methods for sugar production over a wide variety of soils and climatic conditions (except under very high temperatures), and local confirmation of logical choices is all that should be necessary. Similarly, adequate processing machinery is available. Local adaptation should, therefore, present few difficulties, although marketing and distribution could pose problems. Almost all African countries will have to train intermediate technical staff in both field and processing phases of sugar production.

The principal continuing research needs are thus in the fields of plant breeding, plant nutrition (the relationship of crop, water and soil), water requirements under dry climates, and crop protection–especially control of smut disease–assuming that adequate site survey research on soils and climate has been carried out. Varieties and cultivation practices–especially those that promote the number of productive ratoon crops (the second or third crop that sprouts from the rhizomes after the cane has been cut from a new planting) and crop protection–must be adapted to the local environment of a production center.

RESEARCH CAPABILITIES

The FAO *Index of Agricultural Research Stations in Africa* (Webster, 1963) lists a number of stations in several countries with an interest in sugar research, but the only large multidisciplinary research effort on sugar outside South Africa is in Mauritius, where the Sugar Industry Research Institute backs up the very important export trade in sugar and carries on research work in many fields, including cane breeding. Many other research stations–notably in Kenya, Nigeria, Swaziland, the Malagasy Republic, Senegal, Ivory Coast and Niger–are involved in selection, phytopathological, entomological, and other studies. A centralized cane breeding station has been set up under EAAFRO to serve the needs of Kenya, Tanzania, Uganda, and perhaps other countries fringing the East African Community. Seedlings from the center are distributed and tested for disease resistance and other characteristics at production sites throughout the three countries. There has been a clear tendency for governments to leave general agronomic problems to the companies operating the plantations.

Soil survey resources are probably adequate to select good sites for sugar production in any country. Agroclimatic surveys are required for a wide variety of purposes. Consultants may be needed to assist in interpreting the data and in establishing a broad irrigation regime, but large-scale research is hardly necessary. Crop protection studies are certainly needed, but they could probably be supplied as part of the general crop protection services, not as a special service for sugar.

The real research need for sugar production is in the breeding and selection of new varieties that have high sucrose content, that are closely adapted to the local environment—particularly in respect to temperature and daylength—and that are as resistant as possible to the local complex of diseases. However, it is not feasible to set up sugarcane-breeding sites that do not apply to production. For example, minimum temperatures must not fall below prescribed limits, but there must be sufficient change in day length to ensure that canes flower, en masse.

The pattern adopted by EAAFRO has merit: breeding and crossing are carried out at a warm, disease-free site away from the equator, and testing and selection are done elsewhere in the region. But it is questionable whether the central breeding station is strong enough to cope with a larger area and a wider selection of plant material. An extension of this pattern to a worldwide scale has attractions, and links between African stations and the centers in Hawaii, the West Indies, India, Mauritius, and other places might be established. The international arrangement mentioned earlier for potato breeding provides a model: USDA at Beltsville, Maryland; the University of Wisconsin, Madison, Wisconsin; and CIP, Lima, Peru. Progeny from crosses made in America at these places are tested at the IAR unit near Jos, Nigeria. Large commercial cane-breeding centers are often reluctant to part with good plant material, and the sponsoring international aid organizations would have to be very persuasive for such an international scheme to become effective.

An international assistance program in sugarcane breeding, like many other programs, poses serious problems regarding the spread of diseases. Regional schemes like that in East Africa might have to be limited to unified quarantine zones.

CONCLUSIONS

The individual countries of Africa will undoubtedly continue to promote large-scale sugarcane plantation schemes, partly in response to demands for local consumption but also because of the capacity of this commodity to earn foreign exchange. Large-scale sugarcane plantations, rather than small peasant holdings, appear to be the best way of producing sugar whenever conditions indicate that sugar can be grown economically. Such plantations can well be managed so that they support small associated growers also. This is sound agricultural policy.

The research effort on sugarcane belongs on the one hand to industry but, on the other, it needs support from the public sector. Lines of research, such as the study of the incidence of schistosomiasis among people who work in the new irrigation systems or a study of the utilization of sugarcane by-products for cattle feed, should certainly draw some support from the public sector.

IX

Selected Beverages and Kola

Tea, cocoa, coffee and, to a much lesser extent, kola, figure among the most important of the crops grown in Africa for their stimulant qualities. As revenue earners, they contrast with the food crops of the subsistence economies, which were described in the previous chapters. Succeeding chapters will discuss fibers, oil, and other crops that, like these beverages and kola, are grown primarily for export. As export crops, these products have drawn research support from different sources than have food crops. Industrial, commercial, and quasi-governmental organizations, such as producers' associations and marketing boards, levy duties on the cash or export commodities for a variety of reasons, and a portion of these duties have provided the main source of financial support for research. Governments have normally borne directly the cost of research on food crops, although, in some cases, farmers' cooperatives have also helped.

Whether financed by producer, government, or a combination of both, commodity research stations, like organizations such as the International Rice Research Institute (IRRI) based in the Philippines and the International Maize and Wheat Improvement Center (CIMMYT) based in Mexico, which concentrate on one or two economic crop species, run the risk of inattention to the integration of the crop in the farming systems where it is grown.

CURRENT STATUS OF PRODUCTION AND RESEARCH

Although the world market price of tea (*Camellia sinensis*) has remained more or less stagnant over the last 10 years, the crop is still an attractive one for the highland regions of Africa, to which it is ecologically well suited. Costs of land, labor and production there are much lower than the costs to competitors in India and Ceylon. Tea is rapidly becoming a cash crop for small farmers, especially in Kenya but also in Uganda, Tanzania, Mozambique, Malawi and the eastern part of Zaire. Rhodesia, Mauritius, Rwanda and Burundi are small producers with scope for limited expansion.

The cocoa plant (*Theobroma cacao*), native to Latin America, has been introduced into Africa (Figure 10) with such success that, for 1970–1971, Africa provided some 75 percent of the total world production. Ghana, Nigeria, the Ivory Coast and Cameroon are now among the world's principal producers, and considerable progress has been made in the Congo, Zaire, Gabon, Liberia, Sierra Leone, the Malagasy Republic and other countries. Economically one of the most important crops in Africa, cocoa is exported principally to Europe and North America. For Africa as a whole in 1969, 75 percent of the cocoa produced was exported, with a value of $570,272,000.

In recent years, the importance of coffee (*Coffea* species) as an economic commodity in Africa has risen markedly along with its popularity. In 1969, total African coffee production was 1,312,000 metric tons, 984,230 metric tons of which was exported. For Africa as a whole, earnings from coffee exports in 1969 were $651,320,000. The profitability of coffee as a crop for the small farmer in the highlands of Africa is receiving increased attention.

In West Africa the kola nut (*Cola* species) is an indigenous forest product of great economic significance. It is not yet grown on plantations, although it could be an export crop. This product has served as a balancing element in trade between the African countries since at least the fifteenth century. Subject to serious damage from fungus in storage, it would provide an interesting case study from a marketing point of view, as the existing African system of marketing kola is extremely successful. Kola is profitable, and it competes well with other stimulants; in fact, it is more popular than cocoa with the local population.

Tea research has concentrated in the past on clonal selections, the development of vegetative propagation techniques, pruning techniques, fertilizer and water requirements, and the effects of shade on production. Improved processing of tea for quality has also received attention.

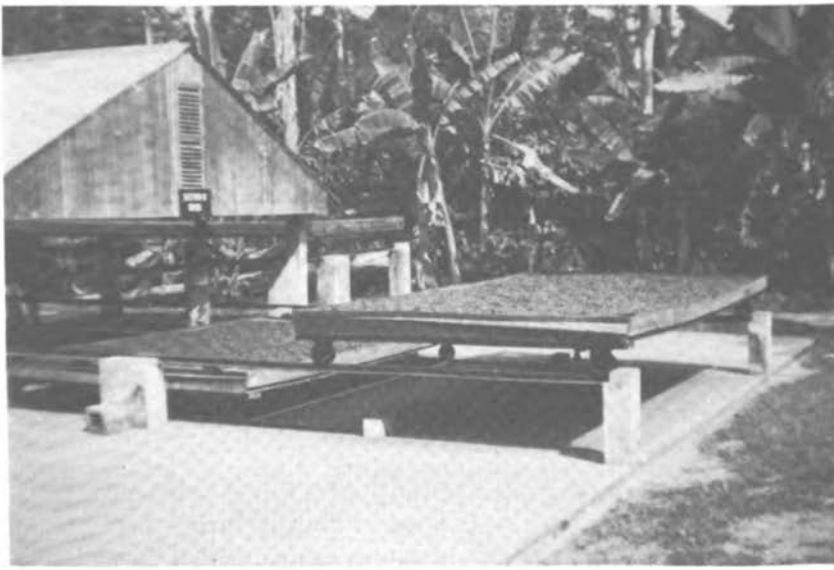

FIGURE 10 Cocoa drying, Bunso, Ghana.

Cocoa has been, and is, the subject of propagation, management, breeding, and disease and pest control research. In propagation and management many problems have been solved—for example, the raising of cocoa seedlings in nurseries, methods of transplantation, land preparation, shading, spacing, thinning and seasonal effects on seed germination. In breeding, much work has also been done to create superior genotypes that combine improved commercial qualities, such as higher yields from hybrid vigor, establishment ability, early fruiting, tolerance of or resistance to diseases, lower production cost and many others. In pest and disease control, some of the most productive research has been that directed toward understanding the biology of capsid insects (mirids), the swollen shoot disease and *Phytophthora* pod rot, and devising effective methods for their control.

As is the case with a number of other economically important crops, much of the outstanding research toward higher yields and efficient production of coffee has taken place at the frontiers of the plant's intrinsic range. Indigenous to Africa, coffee spread to Latin America, where researchers at Campinas, Brazil, and Chinchina, Colombia, among others, have done outstanding research on varietal improvement, agronomic practices that relate to coffee grown in full sunlight in comparison with coffee produced under shade conditions, and other aspects of the physiology of the coffee plant. Important research on disease and pest control has also taken place in Africa. Exhaustive research on coffee rust in Africa was prompted by fears that it would reach other coffee-producing parts of the world. During the past several years the disease has become prevalent in Brazil. The coffee berry disease has been under similar investigations, especially in Kenya, for the sake of Africa's own coffee industry.

Research on kola has been undertaken at Moor Plantation in Nigeria in years past, and today investigations on this crop are centered at the Cocoa Research Institute of Nigeria. The 1965–1966 annual report of CRIN (CRIN, 1966) describes research projects on storage, germination, pruning, shade density, mineral nutrition, insect pests and diseases of the kola root, leaf and nut.

RESEARCH NEEDS

On tea, one of the most fruitful research areas would be breeding programs to upgrade plant stocks, to improve the quality and shelf-keeping character of tea. Vegetative propagation, a technique that has contributed to considerable progress during the last decades, is not adequate for the above requirements, nor can it improve the architecture of the plant. Ninety percent of the crop from tea comes normally from 30 percent of the bushes, and the good quality of those bushes that do produce heavily does not carry through to the selection of cuttings made from them. Not even the architecture of the plant seems to be inherited in the way one would normally expect, and research is needed to explain these results.

Varietal crosses are necessary, but they require research programs of a 20–30-year duration, and existing research stations are rarely prepared to consider programs of more than 5–10 years of continuity. It would be a challenge to African agriculture to develop a cadre of plant breeders of perennial crops—tea as an example—to develop expertise and to produce high-yield varieties of good quality for the future.

If the efficiency of cocoa production in the producer countries of Africa is to be improved, one necessary objective is the control of pests and diseases. The priority accorded them varies with the severity of their occurrence in the different cocoa-producing countries. The cocoa swollen shoot virus is regarded as the most serious disease in Ghana, while black pod rot (*Phytophthora* pod rot) receives the greatest attention in Cameroon. Many insect pests, but especially capsids (mirids), affect the cocoa tree and bring about considerable reduction in yields. Detailed studies on their biology, prevention and control still constitute fruitful areas for research. Maintenance of the proper insect population in the groves for fertilizing the flowers constitutes another quite different but important problem.

The economics of coffee production will greatly influence the sort of research programs planned for the future in Africa. If Kenya, for example, continues to favor producing high-quality *arabica* coffee, its research efforts will be substantially different from those stemming from a decision to respond to the increasing market demands of the instant coffee trade for the *robusta* species.

One leading avenue of coffee research in Africa may be intensive studies of the possible transformation of this perennial species into a functional annual. Work on coffee at Ruiru in Kenya has shown that some forms, at least, of *Coffea arabica* tend toward an annual physiological type. Heavily manured and intensively cared for, they virtually yield themselves to death over a very short period of time. Further research pushing the yield of berries to the absolute capacity of the plant and shortening its life may prove exceedingly useful, especially for environments where diseases and pests build up in perennial plantations over time to excessively damaging proportions.

Until recent years, the selection of *arabica* coffee was based on a limited number of genotypes emanating from seeds harvested in Ethiopia and subsequently introduced into Latin America. ORSTOM, and the Institut Français du Café, du Cacao et Autres Plantes Stimulantes (IFCC) have decided to launch an important program on the structure, morphological development and genetic variability of coffee. Particular attention in this work is given to varieties selected over a long period in the Ivory Coast, and to hybrids produced recently between *C. arabica* and *C. canephora* (*robusta*).

RESEARCH CAPABILITIES

The strongest capability for tea research is in East Africa, especially Kenya. It is sponsored by the tea boards of Kenya, Tanzania and Uganda, which include representatives of the governments and of the industrial concerns that produce and sell this crop nationally and internationally. At Kericho, Kenya, a compact group of about 12 researchers has been examining such topics as the vegetative propagation and effects of fertilizer practices on root growth of the tea plant. A close correlation seems to exist between root development at soil surface levels and leaf mulch, which may be why this crop with its system of spreading secondary roots does so well in tropical areas under shade as compared with its cultivation in direct sunlight.

The Kivu Experiment Station in Zaire is likewise developing an active and innovative tea improvement program in response to the popularity of tea as a crop in the highland areas of that country.

Current research facilities for cocoa may, on the whole, be considered satisfactory. In francophone Africa, IFCC supports the efforts of three governments at centers where highly qualified research scientists and technicians are currently working in the Ivory Coast, Cameroon and the Malagasy Republic. In anglophone Africa, the Cocoa Research Institute of Ghana (CRIG) at Tafo and CRIN at Gambari, Nigeria, have well-developed research programs. Studies on fertilizer use, control of insect pests–especially capsids (mirids)–plant spacing and thinning, germination, root diseases, *Phytophthora* pod rot, and breeding are under way. A large amount of germ plasm was collected in Trinidad and in South America for introduction in Nigeria.

The research facilities for coffee, like those for cocoa, may on the whole also be considered satisfactory. To those in francophone Africa that are part of the IFCC network of stations may be added the coffee research station at Ruiru in Kenya, one at Jimma in Ethiopia, and stations in Tanzania, Uganda and Burundi.

CONCLUSIONS AND RECOMMENDATIONS

For some time to come, Africa will continue to depend upon a narrow range of export crops–among them coffee, tea, cocoa and kola–for foreign exchange and economic growth. These crops are under severe competition from those grown in other parts of the world. A sustained effort will be necessary to make the technology of production of them more efficient and so to decrease cost.

Resources for research are scarce, and the Committee has recommended that priority be given to research on food production for the domestic market. This poses the issue of how to finance necessary research on the export crops as represented by coffee, tea, cocoa and kola.

- *The Committee recommends that the funds required for commodity oriented research on coffee, tea and cocoa be raised, as they have to a large extent in the past, by utilizing institutions such as producers' associations and marketing boards to collect specific taxes on each unit of production of export commodities.*

A number of fascinating opportunities could unfold for modern research on the stimulants. The tea-growing countries of East Africa, for example, need experts in perennial crop breeding for long-term programs to create new hybrids. To develop such a cadre will require the participation of the faculties of agriculture in preparing men and that of the research institutions to design programs of the 20- to 25-year duration required. On cocoa, cultural and breeding practices are now sufficiently advanced that the main problem is one of applied research and extension of existing knowledge for use by farmers. The control of pests and diseases of this crop is very complex and costly and not entirely satisfactory under existing methods. Research efforts will need to be flexible and attuned to the changing pest and disease pattern of this crop as its cultivation becomes more intensified. With respect to coffee, the challenge lies in raising the ceiling on yield and developing new physiological and morphological types to the point where it may become profitable to grow coffee as an annual, enabling it to escape the diseases and pests it currently faces grown as a perennial. Research on kola has barely begun, but the efforts now under way, searching for high-yield varieties and improved cultural practices at the Cocoa Research Institute in Nigeria, should be strengthened.

X

Fibers

Among the many fiber crops that grow in Africa, cotton and sisal are the ones produced and sold on a commercial scale. Cotton has a widening local market in Nigeria, Ethiopia, Uganda, Chad, the Central African Republic, the Ivory Coast and the Cameroons. The Ivory Coast, for example, which harvested 10,000 tons of cotton six years ago, now produces nearly 60,000 tons annually. The government there has built gin mills and factories for spinning and weaving cloth to meet internal needs.

The sisal industry, confined largely to the East African countries, has deteriorated in recent years because of lessening demand for the end products, i.e., agricultural twine, and increased competition from synthetics. Costs of producing synthetics may rise markedly, however, because of energy requirements in their manufacture, and the demand for natural fibers may improve as a consequence. Only in Tanzania is sisal currently a major export crop (Figure 11); although Angola, Kenya, Mozambique, and the Malagasy Republic all produce some sisal. Most of the sisal research in Africa has taken place at Mlingano in Tanzania and in the Malagasy Republic and concentrates on the production of high-yield hybrids, improved methods of harvesting, nutrient deficiencies, etc. The outlook for an expanding sisal industry is limited.

Several African governments have promising programs for developing

FIGURE 11 Cutting sisal, Tanzania. (Photo courtesy of Lynn McLaren, Rapho Guillumette Pictures, New York.)

the production of kenaf and allied fibers for the local industries. But these fibers, when compared with cotton, have slight potential, and, since the potential for sisal is uncertain, this chapter deals with cotton.

COTTON

A diploid cotton was widely grown as a peasant crop in tropical Africa until almost completely displaced by tetraploid American cotton after A.D. 1500. For a century and a half in Egypt, and in many other African countries during the past 50 years, important cotton-growing industries have been developed, originally to produce cotton very largely for export. In recent years local textile industries have also been developed in many countries, and consequently farm production has been expanded and new types of cotton have been bred to supply the new needs. In these ways the cotton crop has served not only to develop sales off the farm—one of the first steps in rural development—but also to provide the raw material for important indigenous industries that diversify national economies and save foreign exchange.

The old cottons in Africa were often perennials; the modern commercial forms are derived annuals. Cotton keeps on growing and producing flowers and is classed therefore as indeterminate; it is variable in fruits and lint characters so a wide range of forms is available or can be produced. Given the appropriate agronomic techniques, the crop can be adapted to an extremely wide range of environmental conditions, although in wetter regions harvesting is often difficult and the lint may be spoiled by rain.

Cotton is a main crop in some large-scale (often irrigated) systems like Sudan's Gezira, but most African commercial cotton is a cash crop in systems that also have to provide subsistence for the farm family. Consequently, it competes with the staple crops for early-season labor as well as for land.

Several potentially serious diseases–virus leaf curl, cotton wilt and bacterial blight–and a large number of insect pests (some of which are also stem borers of maize, sorghum and the millets) attack cotton crops. The biology of most of the disease organisms and pests is reasonably well-known. Varieties have been produced, which if not immune are resistant to some of the diseases (notably, blackworm) and to some insect pests (e.g., jassids); and insecticide treatments have been devised for those insect pests that cannot yet be controlled economically by other means. Sophisticated biological and biochemical means of controlling cotton insects are constantly being sought in cotton-growing countries in other continents, and as new practical methods become available they will no doubt be tested in Africa by the existing research organizations.

Cotton breeding has the almost unique advantage that all or most of the seed produced by farmers each year is sold with the seed cotton at the ginnery, which usually issues next season's seed as well. In this way the breeders can control national or regional seed stocks at will and introduce new varieties rapidly and easily.

Most cotton research hitherto has aimed at maximum yield. Not uncommonly, the recommended practices advise sowing and other operations at times when the farmer and his family have other things to do, and they are usually based on varieties that will do best only if sown at the recommended time. This is part of the reason why farmers' yields in Nigeria still average around 300 kg/ha, while the maximum-yield trials at Samaru consistently produce more than 2,200 kg/ha.

A new round of research has now started (at Samaru, for example) to develop cotton production systems. Systems will include using varieties and protection procedures that better fit into the seasonal availability of the farmer's resources of power and other inputs.

Since cotton earns cash, it could (like other cash crops) pay for fertilizer and for weed control. Where these have positive residual effects, they could help to increase yields of later crops; although the farmer would not reap the full benefits in a shifting cultivation system. Research on fertilizer usage and weed control practices, adapted to local situations, may therefore often be justified beyond the direct effects on the crop.

But the poor yields obtained by most farmers at present cannot pay for more than a minimum of purchased inputs. As in the case with disease and insect control procedures, therefore, research with cotton on fertilizers and weed control is unlikely to lead to adoption of research results by farmers, unless these results are used in production systems correctly adapted to the farmer's goals, opportunities and resources.

Cotton, a valuable crop subject to a variety of devastating pests and diseases, often accounts for excessive use of noxious chemicals as pesticides. Some of the cotton pests have become resistant to some insecticides. Secondary pest problems have also appeared where insecticides have been used persistently or excessively. In some cases these and related problems have led to serious economic consequences. Such consequences can be mitigated by applying good cotton pest management practices based on integrating insecticide applications with other control methods in accordance with the *need* for control (determined by pest population buildup rather than upon a *schedule* of applications determined by the calendar).

Where a cotton system uses long-season varieties sparsely planted, the soil is necessarily exposed to rain splash and the risk of "slicks" until the soil is more or less completely covered by the leaf canopy. Systems spacing cotton closer together may well be more appropriate to areas where wide spacing increases runoff and restricts penetration of water into the profile.

Constraints on cotton growing can also be altered by changes in competing parts of the system. Planting a high-yield variety of one of the food crops in the system, for instance, might lessen the area of land the family needs to grow food. The demand for early-season labor and time would therefore also decrease, and these resources would then become available for the family to use at critical times for growing cotton.

RESEARCH NEEDS

Research on the efficiency with which the cotton plant uses water should be encouraged. A good deal of cotton is grown under irrigation in Africa; in at least some instances this practice has encouraged the use of varieties that take a long time to mature, and long-season varieties appear to use water less efficiently per unit or product than shorter-season varieties do.

Research aimed at full mechanization, especially of the picking operation, should be undertaken where it is clear that the results will not adversely affect employment prospects. The mechanization of picking operations and spraying operations is already advanced on large schemes; hand-spraying methods are employed by small-scale farmers, but these, too, must be improved to reduce labor costs.

Where labor is scarce or expensive, herbicides are necessary to control weeds. Cotton is extremely sensitive to hormone weed-killers like 2,4-D, and so the search must go on for other kinds.

Perhaps the most important breeding objective is to produce a succession of improved cottons which can meet the changing needs of local and world markets in a time of great change for the textile industries.

Many African cotton systems need to be altered so that they use shorter-season forms, perhaps grown in denser stands and sown outside the period of peak labor demand. This is not in itself a difficult breeding problem; but of course all new varieties have to meet quality standards, and this inevitably lengthens the time they require to mature. In many cotton crops, early-formed bolls, which could add to yield and quality, are lost for reasons that are not fully understood. Internal competition for nutrients may be responsible; shading within the crop, and the accumulation of ethylene beneath the somewhat closed canopy, have both been suggested as associated or causal factors. The well-known vertically held, deeply digitate "okra-leaf" character looks as if it could alter the geometry of the crop canopy so as to decrease these losses—at least in areas where the season is short—and it would be of great interest to study this experimentally in comparative trials using varieties bred into a defined concept of plant type, i.e., to test "okra-leaf" against otherwise similar varieties in which the leaves are held more horizontally.

The more effective breeding of pest- and disease-resistant varieties should continue vigorously. Here the important characteristics that influence plant resistance to insects are abundant production of gossypol in the vegetable parts, absence of nectaries and bractless bolls.

RESEARCH CAPABILITIES

Organizations to support the production and handling of the cotton crop are well developed in several countries of Africa so that the results of research can move readily into practice. The Cotton Research Corporation (CRC) and l'Institut des Recherches du Coton et des Textiles Exotiques (IRCT) cooperate with national organizations in research in anglophone and francophone areas, respectively. Parallel institutions for cotton exist in Angola and Mozambique. Capabilities for research on cotton in Zaire are virtually nil; cotton production in that country merits a good research program.

CONCLUSIONS

Cotton, a commodity that stimulates competition among many nations for its value on world markets and that benefits from excellent research programs based in many parts of the world, should receive a substantial research effort in Africa, in part to assure an adequate supply of this fiber to the growing local textile industry. Breeding should be directed toward creating varieties appropriate to local needs and to the place of cotton in the evolving farming systems of the dry tropics. Improving hand-spraying techniques to reduce labor costs constitutes an important research objective, not only for cotton but for other crops, which the small-scale farmer plants, that need protection from pests and diseases.

The importance of cotton in national economic development in Africa also suggests that additional support should be provided, if it is requested, through external aid.

The specialist French and British organizations, which in practice achieve a degree of regional cooperation in cotton research, need to seek ways to improve the farm systems that include cotton as one of many crops, rather than to work for "maximum yield" of cotton in isolation.

XI

Oil Plants

The oil plants of Africa include annuals adapted to dry temperate climates and tree crops that do well in the humid tropics. Examples of the former are nueg (Niger seed, *Guizotia abyssinica*), sesame (benniseed) and groundnuts; soybean may become one of these. The tree crops are primarily the oil palm and the coconut. These oil crops, taken together, enable African countries to utilize large areas of land to produce oil for local consumption and for export to earn foreign exchange.

NUEG AND SESAME

Nueg, an Ethiopian crop, is primarily of local value, and research applied to this crop may best be undertaken at the national level. Sesame, widely grown, yields a high quality oil and a protein-rich oil cake. It has not received the attention for research that it deserves despite worldwide interest in it. High-yield varieties have not been developed, and it is pointless to apply fertilizer to the existing varieties, which do not have the capacity to use it. The unfortunate propensity of the fruit capsule of most varieties to shatter when mature impedes the use of mechanical harvesters. However, the discovery of a nonshattering mutant in 1943 has led to the possibility of complete mechanized production of this plant. Though the original mutant has not itself been useful, a somewhat similar (paper capsule) mutant appears to be more promising.

GROUNDNUTS

Current Status of Production and Research

The groundnut (*Arachis hypogaea*), better known in the United States as peanut, constitutes one of the more important food legumes in the tropics and subtropics–but groundnuts have some disadvantages. Although the seed contains about 25-percent protein and 40-percent oil, the quality of the protein in groundnuts is unfortunately not as good as that of other grain legumes. It is relatively low in lysine, methionine, and threonine (3.5, 0.96, and 2.7 percent, respectively).

As in most (if not all) legume seeds, there are reports of antimetabolites as well as flatus-producing factors in groundnuts. Recent experiences of severe animal poisoning due to aflatoxins in groundnuts or groundnut meal have led to accelerated research on this problem. Aflatoxins are poisons produced by the metabolism of a certain strain of a soil-borne fungus, *Aspergillus flavus,* which enters the ground with the seed particularly in humid climates when harvest is delayed or when groundnuts are not properly cured and stored.

In Africa, as elsewhere, groundnuts are grown mainly for oil. This crop has a total world area of 17.6-million hectares, which produces about 15-million tons/year. With 28 percent of the world production, Africa runs a close second to the subcontinent of India, which has 30 percent. (See Figure 12.)

Low yields in groundnuts are due mostly to poor production practices, heavy losses due to insects and diseases, harvest losses and unfavorable marketing conditions. The low prices paid on the world market to African producers discourage them from using herbicides, insecticides, and other techniques costly in cash or labor, which are essential for achieving high yields and good quality.

Groundnuts are inherently difficult to produce in wet regions; in wet soil the maturing fruit may be attacked by the *A. flavus* fungus. It may well seem undesirable therefore to give priority to research efforts intended to obtain high-yield varieties of groundnuts for the humid tropics.

Most producers try to time their crops to ripen as the rains end, but since the effective end of the rains is unpredictable, the crops tend to ripen either too soon (leading to a wet harvest and aflatoxin and drying problems) or too late (so that they are short of water in the critical last two or three weeks). For this reason and others, drought resistance has received much attention. These general agronomic questions have to be studied locally and regionally.

FIGURE 12 Pyramids of groundnuts, Kano, Nigeria.

On light soils in dry regions, erosion hazards are significant and labor requirements are large. Farmers working by hand cannot sow enough seeds as close as is necessary for satisfactory results with the short-season varieties they must plant. Therefore, simple mechanical seeders worked by human or animal power, like those widely used in Senegal, can offer real advantages to farmers.

Seedbed losses from insects and plant diseases can be heavy, but simple and inexpensive means of chemical protection of the seed are already in use. It may become possible to add a systemic insecticide, like menazon, to the fertilizer dressing in places where aphids are likely to enter the crop fairly easily. Damage by *A. flavus* to mature and harvested fruit and seed can be lessened by good field technique, but the problem is so serious that all promising new research ideas should be supported.

The most important diseases of groundnuts in Africa are the *Cercospora* leaf spots and the aphid-borne rosette virus. Chemical control of both is possible, but the new forms of resistance recently discovered in wild species should be exploited in Africa. Meanwhile, rosette-resisting varieties that have been selected within *A. hypogaea* could increase farmers' yields greatly.

The reproductive efficiency of the groundnut is quite low. Only a relatively few flowers (estimated at 10–20 percent) form fruits and reach maturity. Less than one third of the flowers are fertilized and reach the fruiting stage, and many that do are subsequently lost.

If the reproductive efficiency of the crop can be improved and field losses from diseases and insects reduced, very likely present yields can be more than doubled. If, in addition, farmers adopt better crop management practices, yields of 5,000 kg/ha seem feasible. Such yields have already been recorded from research stations.

Research Needs

Selection has done much to improve yield, disease resistance, and quality in groundnuts, but groundnuts still have insufficient resistance to rosette and no true resistance to *Cercospora* or *A. flavus*. Short-season forms with at least a moderate quality of dormancy in the seeds need to be emphasized in breeding for multiple cropping systems in dry regions. Utilization of groundnut residues for livestock feed is another important subject for research.

Research Capabilities

Research on groundnuts is conducted in most tropical African countries, but the strongest centers at present are in Senegal and Nigeria. In Bambey, Senegal, the Institut de Recherches Agronomiques Tropicales et des Cultures Vivrières (IRAT) is conducting studies on varietal improvement, cultural practices, fertilization, pests and diseases (*Cercospora,* other fungi, and rosette virus), and aflatoxin, in cooperation with the Institut de Recherches pour les Huiles et Oléagineux (IRHO) in Upper Volta, Mali and Niger. At the Samaru and Kano stations of IAR in Nigeria, studies are under way on varietal improvement, cultural practices, the agronomic aspects of mycotoxins, and breeding for high oil content and for resistance to *Cercospora* leaf spot and rosette virus. In Gambia, research on varietal improvement and agronomic trials are being carried out at the agricultural station, Yundum, of the Gambian Department of Agriculture whose headquarters are at Cape St. Mary. The Grain Legume Research Laboratory of the Agricultural Research Council of Central Africa, located at Lilongwe, Malawi, and Mount Makulu Research Station in Zambia are significant. At Lilongwe, research is centered on varietal improvement and resistance to *Cercospora* leaf spot and rosette virus. Researchers affiliated with the East African Agriculture and Forestry Research Organization (EAAFRO) have been conducting studies on the rosette virus complex and have identified five separate viruses involved. Earlier work in the Sudan and in Zaire is not markedly reflected in current activity in those countries.

During the past ten years, the groundnut program at the University of North Carolina (Raleigh) has made important studies of new *Arachis* materials from South America, where the plant originated, and new sources of variation and of resistance to pests and diseases have been found and are now available. Efforts should be made to associate these studies with one or more of the main African centers for genetic and breeding work. The most appropriate center in the anglophone region might be IAR at Ahmadu Bello University, Nigeria, but there may be others in which these botanical studies can be productively associated with practical plant breeding and agronomy.

SOYBEAN

Current Status of Production and Research

The soybean (*Glycine soya*) is an attractive new food legume for African countries because (1) it can give large yields of acceptable protein and semi-drying oil; (2) it can be harvested mechanically; and (3) it does not present the aflatoxin problem of groundnuts.

But in Africa, a continent already well-endowed with a variety of fine oil-producing crops, soybeans do not form part of indigenous diets and may have difficulty in competing with other major oil seeds. In no country of Africa does the yield of soybeans per hectare as yet exceed that of groundnuts. Many of the soybean varieties studied hitherto in Africa have been so sensitive to short days that their yields have been often very small.

Varieties from tropical Southeast Asia, day-neutral forms from high latitudes in East Asia, and subtropical forage types will surely make it possible to breed forms that will yield well anywhere in the African tropics. Some United States introductions appear to have as much as or more promise than Asian ones. Screening methods to speed such selections are being studied at the University of Reading, England, in cooperation with the International Institute of Tropical Agriculture (IITA).

African farmers rarely plant soybeans because of a presumed lack of yield potential, and the African public does not eat them. To encourage the African farmer to plant soybeans, demand must grow among the African people for soybeans as a palatable and useful part of their daily food ration. African farmers will have to pay attention to some special agronomic idiosyncracies of soybeans. They need to be sown thickly and precisely to produce good yields; the simple seeder used for groundnuts could presumably be adapted for soybeans also. High soil temperatures are a major deterrent to good germination. Inoculation will be essential, at least on soils on which the crop has not been grown before. Soybeans seem to have few crippling pests or diseases in Africa, but experience is limited and vigilance will be essential.

Research Needs

A collection of wild species of *Glycine* from Africa and elsewhere should be grown and studied in Africa, perhaps at IITA or Makerere University in Uganda, at an early stage. This work could be undertaken in collaboration with USDA's Regional Soybean Laboratory and the University of Illinois at Urbana, Illinois, and selected stations in the wet, dry, and high-altitude tropics in Africa.

The effects of variety and environment on the balance between protein and oil in the seed (which is thought to be reciprocal), on protein type and composition, and on the undesirable proteins, antimetabolites and other substances in the seed deserve study.

Plants with pods that remain closed as they ripen in the increasing heat and drought of the early dry season in Africa will have to be bred.

Research Capabilities

There are limited capabilities for research on soybeans in Africa at present. Interest in its production has been generated in Kenya, which is looking for a cash crop alternative to maize at EAAFRO, which serves the three East African countries; in Tanzania; and in Uganda at Kabanyolo Farm of the Faculty of Agriculture at Makerere University. In Nigeria, IITA has initiated trials of varieties to ascertain the potential of soybean as a food legume in the humid tropics and also a comprehensive breeding program with soybeans. Some breeding and agronomic work on soybeans has been done at Mokwa and at Samaru where much higher priority is to be given in the future to soybeans.

COCONUT

Current Status of Production and Research

The African countries, notably Mozambique, the Ivory Coast, Dahomey and Togo, account for less than 2 percent of the world's production of coconut; 90 percent is in Asia and Oceania. The world average yield of copra is 600 kg/ha, but through plantation culture of high-yield varieties and the use of advanced techniques, yields of 4–5 tons are possible. If the improved varieties now available in Ivory Coast were extended to all the coconut-growing countries of West Africa, the 1,600 kg/ha average production of copra from local varieties could rise to 4,000–5,000 kg/ha.

Years ago the coconut palm also received attention when the South Pacific Commission of the NAS Office of the Foreign Secretary searched in East Africa for parasites and predators to control the coconut rhinoceros beetle. This beetle, a devastating pest in the South Pacific, too, feeds on the apical bud of the palm tree, often killing it. Temperature, moisture and altitude ranges for coconut growing—in effect, how far from the sea it can succeed—are other areas for investigation. Leaf analyses to determine mineral deficiencies and fertilizer requirements, and to facilitate work on selecting high-yield varieties for specific environmental conditions, have been under way in Ivory Coast for some time.

Special problems in research have appeared on coconut in Africa. One of these is the *kaincope* disease in Togo. According to recent research on a similar disease in Jamaica, it may be due to a mycoplasm, probably transmitted by leafhoppers.

Research Needs

One of the priority research areas for coconuts concerns its potential comparative advantage in tropical agriculture. This research should be done with respect to both the domestic food market and the international market for copra and coconut oil. Such research requires the cooperation of economists and technical experts and researchers. Assuming that the results warrant a program at all, the various potential research programs should be examined with respect to prospective payoffs in breeding and selection, disease and pest control, cultivation and management, and the production, handling, processing and marketing of copra. Research should also be begun on the economics of coconut farming patterns (smallholdings, private estates, or state-owned plantations) and on growing coconut palms in combination with other crops, and with animal production.

Research Capabilities

Such research as is undertaken in Africa may be more significant as it relates to coconut production in other parts of the world where it would seem that the coconut industry ought to support the bulk of research on production. Ample capabilities nevertheless do exist in Africa to study the coconut as an oil crop; these at present lie in the francophone countries through IRHO.

OIL PALM

Current Status of Production and Research

The fruit of the African oil palm (Figure 13) yields oil in two different ways. Oil is extracted from the pulp of the fruit; this oil has been produced for domestic consumption in Africa throughout recorded history and has been exported since the late eighteenth century. Oil is also extracted from the kernels of the fruit; palm kernels have been exported since the mid-nineteenth century. Palm oil and palm kernel oil became more important following research in Zaire (then the Congo) that demonstrated the hybrid nature of the thin-shelled *tenera* fruit, and thereby made possible an increase in the palm oil yield of about 45 percent in Africa with no increase in bunch yield. Palm oil could then compete favorably with other vegetable oils, particularly soybean oil, in the export market.

FIGURE 13 Oil palm fruit. (Photo courtesy of Dr. Edward S. Ayensu, Smithsonian Institution, Washington, D.C.)

In West Africa a considerable technological research capacity has developed, concentrated largely upon the extraction and processing of oil from large-scale oil palm plantations.

A large proportion of the palm oil and kernels of West Africa, however, is produced by smallholders who harvest the fruit from wild plants. The Nigerian Institute for Oil Palm Research (NIFOR) at Benin has conducted a series of investigations on presses for the use of smallholders and also on the management of wild groves devoted to the use of oil for food and for palm wine. But more research on the processing problems of smallholders is necessary, particularly with respect to the establishment and maintenance of quality.

Research has concentrated heavily on breeding and the selection of new varieties, pest and disease control and cultivation techniques. In the francophone countries, good research is being done on pest and disease control, particularly on the problems of wilting diseases (*Fusarium* species) in plantations and on blast and *Cercospora* leaf spot in nurseries. Notable success has been obtained in correcting for deficiencies in soil potassium, magnesium and boron; oil yields of 2,500–3,500 kg/ha are now being obtained from the best varieties.

The Ivory Coast has launched a plan for palm oil development and has created a state company (SODEPALM) to produce the crop. Basing its work on the pedological studies of IRHO, SODEPALM had planted more than 60,000 hectares of palm by 1971, starting in the savanna zones of the country and progressing systematically into rain forest areas.

A similar program, though of somewhat smaller scale, has been undertaken in Dahomey.

Research Needs

The economics of palm oil and kernel production have been investigated, but this research has been peripheral to the fundamental interest in increasing yields and in processing. A large-scale research effort is needed on such subjects as the cultivation and management of improved modern groves, the replanting of groves as they become overaged, and on the replacement of wild groves. Such research is fairly location-specific and hence should be done at various locations throughout the palm production area.

Very little significant research has been done with respect to the institutional changes required to support a viable oil palm industry in West African countries. Here the unanswered questions involve the operation of marketing boards that produce revenue for government; other forms of taxation; product prices; producer incentives; the effects of different distributions of income among laborers, smallholders, government employees and plantation owners; and the control and administration of investments in oil palm production.

There are also serious unanswered questions about the comparative advantage of Africa in world oil palm production. Some of these questions are ecological and technological; others are institutional. Cooperative research between palm oil technologists and economists is required to put into perspective all the relevant factors.

Research Capabilities

In the anglophone countries of West Africa before independence, oil palm research was handled by a regional institute with stations throughout the area. The West African Institute for Oil Palm Research was reorganized at independence to form the Nigerian Institute for Oil Palm Research. Its research output declined seriously during the civil war. It will be important to restore its capacities as rapidly as possible.

Among the francophone countries, IRHO supports a network of stations devoted to oil palm research. Three of these are in the Ivory Coast, one in Dahomey, and one in west Cameroon. These stations have been strategically chosen to represent a range of environmental conditions with respect to soil quality and rainfall distribution. The research at these stations covers discipline-oriented research, as well as applied investigations, and even pilot plant operations on oil palm production. Research workers, including the headquarters staff, undertake research covering plant biology and physiology; selection; agronomy and mineral nutrition; plant pathology, insect control, and protection; and preservation and processing of products.

CONCLUSIONS AND RECOMMENDATIONS

World demand for vegetable oils for industrial and domestic use has directed research on the so-called "oil crops" toward maximum oil output to the extent that research to increase the quality of these plants as protein sources for human consumption has all but been neglected (groundnuts and soybeans are cases in point). There are some exceptions to this trend, and the Committee recognizes that, as oil resources, these crops are too vital to the economy of the African nations not to continue to improve their oil content still further.

• *The Committee recommends nevertheless that the imbalance between research on oil and research on protein content be redressed in Africa, especially on groundnuts.*

African researchers have much to gain in developing close relationships with overseas workers in the United States at institutions where research with international emphasis is under way on groundnut breeding, agronomy, disease and pest control. If new varieties or production methods extend the range of the groundnut into the wet regions of Africa, aflatoxin may become an even more serious problem than it is now. Lines of investigation that might minimize aflatoxin concentrations in the produce should be strongly supported.

On a commercial scale, the soybean is a comparative newcomer to African agriculture. It will be essential to develop varieties that will grow and yield well in African soils and under African conditions of climate and day length.

The oil palm, like groundnuts, is bound to face increasingly severe competition from other parts of the world, especially from Malaysia and Indonesia where soils and rainfall distribution appear to be more favorable to high-yield palms than they seem to be in Africa. To maintain or to improve their position in the world market, African growers will need drought-resistant varieties that give large yields of good quality oil. At the same time soil improvement, better mineral nutrition, control of insect pests (leaf miners) and plant diseases (wilt) will be essential.

Like coconut groves, oil palm plantations *per se* have been the subject of experimentation; multiple cropping, the use of cover crops, and pasturing cattle beneath the palms are some of the research areas. Research of this type should be intensified.

The coconut industry of Africa needs a complete overhaul–new stock to replace old debilitated palms and modern methods of pest and disease control. The apparent lack of enthusiasm in Africa to rehabilitate the coconut industry is largely due to the inability to control the coconut pests and diseases. Studies should also be conducted to ascertain the temperature, moisture or altitude limits in Africa within which the coconut palm will thrive.

XII

Tobacco and Rubber

Tobacco and rubber stand out among the wide variety of commercial crops that may be so classed for discussion in this report because of their potential contribution to the economic development of a number of African countries. However, each is sensitive to the vagaries of production on a worldwide scale and to competitive advantages or disadvantages with relation to other commercial crops grown in Africa in any given year. Marketing and production policies significantly influence their fate. Research on them is essential in order that they may increasingly contribute to domestic economies as well as continue to compete for Africa's share of the world market.

TOBACCO

Current Status of Production and Research

Tobacco (*Nicotiana tabacum*), an American plant that spread rapidly throughout Africa after the year 1500, is now widely grown as a domestic crop for family and industrial uses. During the past 30 years, tobacco industries have grown up in most if not all African countries, producing for local consumption and, in certain cases (Rhodesia, Malawi, Zambia, Cameroon and the Malagasy Republic), for the world market. Outside Central Africa, the main growing regions are the West African savanna and East and Northeast Africa (Tanzania to Ethiopia). The tobacco types are usually air- or flue-cured Virginia, burley, or oriental (Turkish); the important export product is bright, flue-cured Virginia leaf, mainly for cigarettes.

Tobacco has several significant advantages for economic development in Africa. Some types can be produced satisfactorily on poor soils and under dry conditions. The value of tobacco per unit weight is large, so that it can bear transport costs from remote areas. Tobacco can also be profitable enough to bear the cost of some purchased inputs. It substitutes for imports and provides raw material for a local industry; and where it is exported, it earns foreign exchange. The tobacco industries in many anglophone countries are associated with the British-American Tobacco Company, which, through its local associated company, often organizes or assists the farmers and also manages the processing, manufacture and marketing of tobacco products. (A similar situation is found in francophone countries of West and Central Africa, where in many places the JOB-BASTOS Company manufactures the tobacco grown under its own supervision.)

The tactical objectives of research are to determine the most suitable places to raise tobacco, the most suitable periods for cropping, and the types and techniques of production appropriate to these places; to protect the crop against pests and diseases in seedbed and field; and to breed varieties better adapted to the agricultural timetable, with resistance to pests and diseases and quality suitable for the market demand.

Most of the current work on production is standard agronomy devoted to disease and nematode control (particularly in seedbeds); cultural practices; fertilizer requirements for specific conditions, varieties and soils; crop rotations and harvesting; and processing procedures.

Quality does not yet seem to be a major agronomic objective in some countries, but it is likely to become more important as the volume of production increases. This goal will require particular attention to the nitrogen–potash balance in the nutrition of the crop.

Numerous insects, often plant and virus vectors, attack tobacco leaves and so affect yield, appearance and smoking quality. The conventional chlorinated hydrocarbon insecticides are generally used to control these pests. They are being replaced by short-lived systemics, which are much less safe for the operators and may indeed be dangerous for peasant farmers. Whether the change offers a large enough increase in safety for the consumer to offset these dangers to the producer is open to question.

As tobacco is grown repeatedly in the same ground, the population of parasitic nematodes will rise. No truly satisfactory measure for combatting them is available, though they can be controlled by soil fumigation (an expensive procedure) or by crop rotation (a long-term measure).

The most serious diseases are blue mold (*Peronospora tabacina*, only north of the Sahara), brown spot (*Alternaria longipes*), wildfire (*Pseudomonas tabaci*), angular leaf spot (*P. angulata*), tobacco mosaic and other viruses, frog-eye (*Cercospora nicotianae*), sore shin (*Rhizoctonia solani*), and powdery mildew (*Erysiphe cichoracearum*).

Research Needs

This extremely polymorphic, day-length-sensitive crop requires sound front-line research linked with extension, credit and marketing services in all areas where it is grown. Such research would support increased production to substitute for imports in meeting internal needs. Some of the commercial tobacco companies could conduct this research at least as effectively as the official services, which would then have more time for other tasks. This in turn would allow the advanced research to be concentrated in a small number of centers, each serving a particular climatic zone or region. Given appropriate arrangements for consultation with official services, a regional center could be managed by the tobacco industries so that the cost to public funds might well be relatively small.

Research Capabilities

Until a few years ago, the Tobacco Research Board (TRB) of Rhodesia and Nyasaland was responsible for almost all tobacco research in Rhodesia, Zambia and Malawi. What remains of it, the TRB of Rhodesia, now conducts one of the most advanced programs in Africa. Researchers there have studied the local biology of the diseases and pests in detail and are undertaking a significant breeding program. It cooperates with the official service in Malawi, on whose behalf it conducts all research on flue-cured, burley and oriental tobaccos.

Elsewhere official research is not strong, but useful adaptive work is done by the local tobacco companies. The Institut de Recherches Agronomiques Tropicales et Cultures Vivrières (IRAT) has undertaken research, mainly on production questions and variety testing, in Dahomey, Niger, Upper Volta, Senegal, Mali and the Malagasy Republic and has assisted tobacco development in Tanzania and Ethiopia. In other places the varieties used are introduced, often from Europe, the United States and Latin America or from other parts of Africa. The

National Agricultural Development Seminar (1971) in Nigeria accords high priority to research on tobacco.

RUBBER

Rubber is an important foreign exchange earner in tropical Africa and an increasingly important source of raw material for African industry; it uses labor intensively and hence is an important source of personal income and employment in West and Central Africa, where a large proportion of the rapidly expanding population will be dependent on agricultural employment for several decades to come.

Present Status of Production and Research

Much of the West African rubber production is carried out by smallholders only slightly affected by government extension, research and development programs, but much is still also planted in large plantations. In Nigeria a few state-owned plantations were established by the government of the former eastern region of the country; in midwestern Nigeria palm oil plantations have in recent years been replanted to rubber, largely because tax policies have removed the comparative advantage of palm oil over rubber. In the Ivory Coast and Cameroon, private companies and the government established large plantations following the war in Indochina. Thus the Ivory Coast initiated a project to plant 30,000 hectares of rubber trees in addition to the already existing 12,000 hectares. Cameroon also intends to extend its area under plantation (21,000 hectares) by 30,000 hectares.

Until recently rubber seemed to be at a natural comparative disadvantage relative to oil palm in Nigeria in that rationalization of marketing board policies would shift expansion of acreage toward palm to the further disadvantage of rubber. Four developments now make this conclusion questionable: (1) the apparent exhaustion of further economies in the production of synthetic rubber, the costs of which now increase with wage rates in the developed countries; (2) the discovery of cost-reducing ways of collecting and processing latex and of processing crude lump rubber produced by smallholders; (3) the disturbances of palm oil production by the Nigerian civil war; and (4) the use of latex-flow stimulants.

The advantage of West and Central Africa in rubber production compared with that of southeast Asia results from conditions of rainfall, sunshine and temperature. While it is often asserted that South Asia has a superior environment for rubber production, it is no longer clear that rubber is at a disadvantage in West and Central Africa *vis-à-vis* palm and food crop production. In addition, any disadvantage that does remain may be erased if improvement in food grain and root crop production technologies in the sub-Saharan areas to the North enable that area to export food to the rain forest belt. The rain forest areas are biologically more "comfortable" when devoted to tree crop production than when used for cultivated, upland annuals with the attendant problems of erosion, leaching, soil compaction and crusting, and loss of organic matter. Rubber, with its deeper feeding root system, can be successfully established where food crops can no longer be advantageously grown, and, like forests, it renews the surface soil with the accumulation of natural litter and recirculation of soil nutrients.

Research Needs

In West and Central Africa, rubber production requires coordinated economic, technological and ecological research to determine whether or not West African rubber production can expand in competition *internationally*, with natural rubber produced elsewhere in the world and with synthetics, and *domestically*, with other West and Central African products (palm and food) that compete with rubber for land and labor. This research must be coordinated because the answers depend on technological progress not only in rubber but also in palm and food production. These crops interact with the ecology of the region. Institutional structures for research and development on them are also built within the economic context of the region. Needed technological research involves the continued production of rubber plants even better adapted to the region (i.e., quality improvement and control, plant nutrition, and plant protection) better marketing and processing technology, and labor-saving techniques. Needed ecological research includes studies on a better overall description of the West and Central African environment. Needed economic research ranges from the design and evaluation of farming systems at the farm or estate management level, through marketing studies, to studies of the comparative advantage of growing rubber or other crops. Agricultural policy at national and international levels will influence and be influenced by these research inputs.

Research Capabilities

Though rubber producers in Africa have relied heavily in the past on improved planting materials imported from abroad, a substantial research capability exists on the continent.

In Liberia, private plantations have carried out much of the research and development activities. The Firestone plantations (Figure 14) conducted extensive chemical and biological research, pioneered extrusion drying, and created several new clones that are widely planted. They did extensive work on latex flow stimulation, disease control and tapping systems. Latex stimulants (2,4-D and 2,4,5-T), employed commercially since 1955, have increased yields an average of 23 percent. A recent discovery, "ethrel" (a compound which releases ethylene), has doubled yield experimentally on a smaller tapping cut (one quarter, as opposed to half of the circumference, which greatly increases the life of the tree), but time must show whether this method has side effects on the physiological behavior of the stimulated trees (e.g., growth of the tree and regrowth of the bark).

In Nigeria, the Ministry of Agriculture and National Resources has taken over responsibility for the administration and support of the Nigerian Rubber Research Institute at Iyanomo, south of Benin City.

Working in Zaire from the station at Yangambi, the Institut National pour l'Étude Agronomique du Congo (INEAC) included a research division for rubber. This division selected plant material and worked at methods of planting, of rubber plantation maintenance and of disease control. In contrast to Malaysian procedures, development with clonal seed obtained from clone gardens was given precedence over bud-grafted material. This work came to an end after independence.

Since the independence of Zaire, l'Institut de Recherche sur le Caoutchouc en Afrique (IRCA) is the only public rubber research institute of international scope working in Africa. It gives technical assistance to the former French territories through two stations, one in Ivory Coast and one in Cameroon, and through technological and chemical laboratories in France. Significant results have been obtained toward improving plant material and planting methods, cultural techniques and mineral nutrition and fertilization of rubber trees, disease control, methods of exploitation, and the quality of the product. Fundamental research has also been carried out in the fields of plant physiology and biochemistry (e.g., latex flow, stimulation, and enzymology of latex).

In Ivory Coast and Cameroon, private companies benefit from the technical assistance of IRCA, and some of the field trials are established on their estates; IRCA also aids development projects in these countries as technical adviser to the governments.

CONCLUSIONS AND RECOMMENDATIONS

The wisdom of accelerating research on tobacco and rubber is a matter of agricultural policy for different reasons in each case. The well-docu-

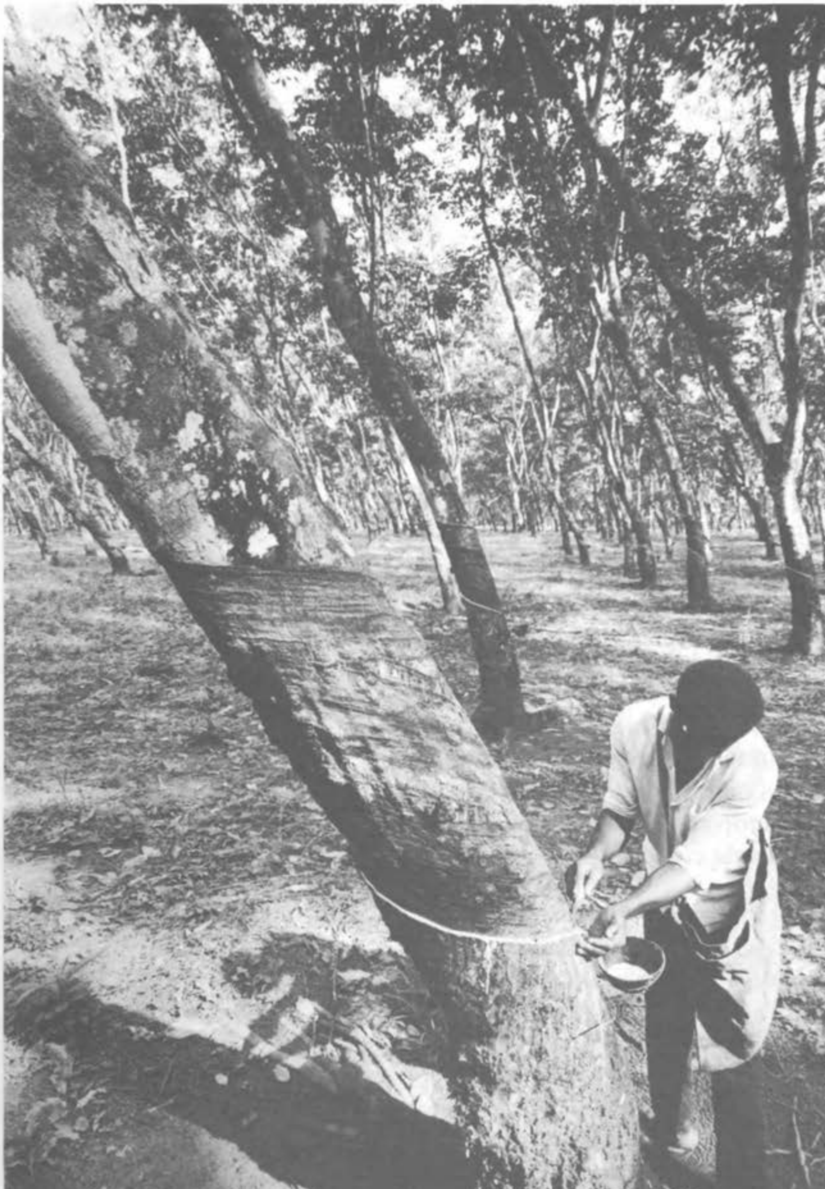

FIGURE 14 Tapping rubber, Firestone plantation, Liberia. (Photo courtesy of Georg Gester, Rapho Guillumette Pictures, New York.)

mented research on the harmful effects of smoking to human health raises the question of the degree to which tobacco production should be fostered and what crops might be planted instead. The rubber question is mainly an economic one–whether or not in the long run natural rubber can continue to compete with synthetics. Notwithstanding these long-term policy questions, tobacco and rubber earn substantial revenue for many of the African countries today. They supply the needs of local industries and conserve foreign exchange. These crops require continued research effort.

- Extension, credit and marketing command the highest priority in tobacco research. *The Committee recommends that tobacco industries take the lead in establishing a strong regional research effort on extension, credit and marketing as well as on the standard investigations of agronomy, breeding and disease control, and thereby reduce the cost to public funds of this research.*
- Economics, technology and ecology are the areas recommended for emphasis in rubber research. *The Committee recommends that research on the economics, technology and ecology of rubber production be strengthened and integrated with similar research on palm oil and on food crops.*

The vitality of the rubber industry in Africa depends upon the farming systems of the humid tropics in which rubber must compete with palm oil and food crop production. Therefore any institute devoted to research on rubber must take a broad program approach characteristic of multicrop stations and at the same time maintain the sharpness in goals that single crop, problem-oriented research provides.

XIII

Animal Resources

Livestock, those domestic animals that people raise to feed themselves and for sale and profit, occupy by far the highest priority among the animals that are assets to agriculture. However, game animals and fish also impinge importantly upon agricultural pursuits. Accordingly, wild species are also important to discussions of the impact of animal life on the continent and of agricultural research needs and capabilities.

DOMESTICATED STOCK

Current Status of Production and Research

Ruminants Of domesticated stock, the ruminants (cattle, sheep and goats, primarily) can utilize vast areas of the African permanent rangeland unsuitable for crops (Figure 15). Some 110 million head of cattle, 180 million head of sheep and goats, and large numbers of wild ruminants now graze this land, providing a way of life for some 40 million people. A number of small farmers and pastoralists do not have the capital to acquire cattle, but they keep sheep and goats. In many instances, the small ruminants–sheep and goats–mingle with cattle on African rangeland; so any analysis of rangeland use must therefore take them into account.

In addition to using permanent rangelands for grazing, domestic animals utilize the by-products of cereals, vegetables and roadside grasses

FIGURE 15 Domesticated stock, Muguga, Kenya.

that would otherwise go to waste. Surplus cereal grain will also find a ready market through livestock. Together, domesticated stock supply the bulk of the animal protein for at least 140 million people. But human population on rangelands and elsewhere is rising, and meat consumption is rising so rapidly that the large marketing centers like Lagos, Nigeria, and Abidjan, Ivory Coast, are becoming concerned about their future meat supplies.

Cattle Cattle are easily the most important ruminants in Africa because of the quantities of milk and meat they provide. Traditionally, cattle are maintained more for milk than for meat, even though the indigenous breeds are relatively poor milk producers. Cattle indigenous to the rangeland cannot supply the rapidly expanding urban markets with milk. For this reason, governments are developing urban dairy operations with imported breeds kept under confinement indoors. The problems of this type of operation are receiving research attention in the Ivory Coast, Nigeria, Zaire, Uganda, Ethiopia and Tanzania. In the highlands of East Africa, European breeds of dairy cattle, managed in European production systems, have been introduced successfully.

The annual offtake of cattle for commercial meat production is less than 10 percent in tropical Africa. Most cattle marketed are thin, weighing about 230–320 kg (500–700 lb), and they are generally over 5 years of age. Meat is usually sold unchilled and is of relatively poor quality. Harsh environmental conditions result in numerous production problems. Reproductive efficiency is low, averaging about 50–55 percent. Heifers mature slowly, having their first calves at 3 1/2–4 years of age. Many of the calves die; up to half are lost in the first year in many countries.

Low planes of nutrition, inadequate water supply, poor management practices, pests and diseases constrain beef production. Except to encourage vaccination against several contagious and parasitic diseases, the considerable amount of research already done on livestock problems has had little impact on traditional livestock husbandry. Basic socioeconomic conditions make the adoption of the new technology difficult; it will be necessary, therefore, to study existing livestock and pastoral systems first in order to understand how they can be changed.

Diseases, such as trypanosomiasis and East Coast fever, present the major obstacle to efficient cattle production. The occurrence of trypanosomiasis in cattle excludes it as an economic source of protein and transportation from 12 million km^2 (4 1/2 million sq mile) of the continent: East Coast fever is equally devastating in what is otherwise one of the prime regions ecologically for producing cattle, the highlands of East Africa. The presence in Africa of foot-and-mouth disease, rinderpest, and contagious bovine pleuropneumonia–highly contagious diseases, which threaten the world's livestock–prohibits the importation of African livestock and their products by most continents and greatly handicaps African economic development. In Africa, impairment of calf development and death due to disease commonly reduce cattle production by 25–50 percent.

Trypanosomiasis, the parasitic disease (*Trypanosoma* species) transmitted by tsetse flies of the genus *Glossina,* either prohibits or greatly impedes cattle husbandry in two thirds of tropical Africa. The rangelands of Africa now unusable for cattle because of trypanosomiasis are otherwise capable of supporting 125 million head–more cattle than presently exist on the rest of the African continent.

East Coast fever and related diseases caused by tick-borne hemoprotozoa (including members of the genera *Anaplasma, Babesia, Theileria,* and *Gonderia*) impose major handicaps on cattle production throughout Africa. Although East Coast fever may kill up to 30 percent of the young calves in some areas, these debilitating diseases cause their greatest damage through decreased production. Costly dipping up to twice a week is necessary in most areas to control ticks. A vaccine developed for at least one strain of East Coast fever now holds new hope for prevention.

Foot-and-mouth disease, a virus disease, imposes a periodic or continuous burden upon cattle production in Africa; it limits the export possibilities to countries that are free of the disease. A debilitating rather than a killing disease, its toll on production tends to be ignored, and efforts to eradicate it have therefore had a low priority. A polyvalent vaccine that will produce at least one year's immunity is urgently needed if the disease is to be eliminated from large enough regions to permit exports to countries free of disease. An awareness of the economic advantages of such exports will probably be necessary before control efforts receive high priority.

Rinderpest, a virus disease, was long the most devastating infectious disease of ruminants in Africa. It is now well under control as a result of a continental vaccination campaign in equatorial Africa, based on a vaccine developed at the East African Veterinary Research Organization (EAVRO), Muguga, Kenya. Eradication of this disease is possible if vaccination is diligently continued in each country; if not, this disease could again rise to epizootic proportions.

Contagious bovine pleuropneumonia, a bacterial disease caused by *Asterococcus (Mycoplasma) mycoides,* is continuing to spread because of failure to mount effective vaccination campaigns. Activating a current plan for a transcontinental vaccination campaign could lead to near eradication of the disease if good international cooperation directed toward complete coverage and research to improve the vaccine continues.

Streptothricosis, a fungal disease affecting the skin of a variety of domestic and wild animals, is most prevalent in cattle in humid regions where tick control is inadequate. It is of varying regional importance.

Cysticercosis (the beef tapeworm) of cattle and man occurs throughout Africa, and in some areas up to 80 percent of the beef is infested.

Sheep and Goats The production and health problems of sheep and goats have received sporadic attention at best, and few of the findings have been put into practice. Work has been done in Kenya in relation to the exploitation of stony ground for pasture. Some expertise in sheep but not in goat husbandry has been centered at the National Animal Husbandry Research Station in the Rift Valley at Naivasha, Kenya. In Nigeria, the University of Ife is looking at the improvement of short-legged goats for the forest zone. The absence of sustained research on these animals suggests a need that should be assessed. For centuries the sleek, chestnut brown Sokoto goat of Northern Nigeria has supplied the markets of Morocco and Italy with the finest leather. No one knows to what extent this goat can be exploited, in the best sense of the word, to yield greatest returns for its skin, meat and milk in the product-hungry, economically stressful desert area of the southern fringes of the Sahara.

Nonruminants Nonruminant animals, particularly poultry, have some advantages over the ruminants; although they consume the same scarce feedstuffs that human beings eat. This is likely to remain an important consideration until surplus cereals and milling by-products can be produced economically. Poultry meat and eggs enjoy wide acceptance. Pork, it is true, may not be acceptable among some religious groups, but among others it serves as an excellent source of protein.

The projections of the Indicative World Plan (IWP) of the Food and Agriculture Organization (FAO, 1969a) call for raising the contribution of pig and poultry meat from 24 percent of the total meat available in 1962 to 47 percent of all meat consumption in 1985. This proportion may, however, become reduced by the year 2000 if the target improvement in ruminant livestock can be attained after 1985. Since the production of meat and other animal products falls much below the rising demand, it is necessary to emphasize the production of these species in a relatively short-term developmental policy to raise the supply of meat sharply.

Research Needs

Ruminants If Africa is to modernize its livestock industry based on ruminants effectively, much research will have to be undertaken. One outstanding need is to bring together the rangeland and pasture surveys that have been made and to synthesize and assess the results. The Institut d'Élevage et de Médecine Vétérinaire des Pays Tropicaux (IEMVT) operating in francophone Africa has already collected and synthesized such information and mapped more than 600,000 km.^{2} On the basis of such a survey, new specific proposals could be formulated for multidisciplinary research.

Research has been successful in the introduction of exotic legumes, notably "stylo" (*Stylosanthes guyanensis*), in tropical Africa, but not enough attention has been given to research on using the tropical grass and legume species whose center of origin is Africa for planted pastures. However, in this area the Office de la Recherche Scientifique et Technique Outre-Mer (ORSTOM) has obtained encouraging results with *Panicum maximum.*

Additional rangeland and pasture studies might include investigations on efficient use of water resources; use of better grazing practices, such as rotation; periodic cuttings; introduction of plants, particularly legumes, suitable in each ecological zone; and evaluation of existing planted pastures and forage crops.

Farming systems research should make it possible to use the bush fallow phase of shifting cultivation to establish and develop livestock and poultry enterprises.

Research on livestock production systems should seek to develop controlled grazing methods appropriate to climatic conditions; to use supplemental feeds such as by-products of cereals, grain legumes, oilseeds, and vegetable crops; and to "finish" cattle through feedlot operations.

Socioeconomic studies must also be conducted that include new, penetrating analyses of transhumanance (the regular movement of people to and fro in an area) and of the economic, as well as the social, significance of livestock in different parts of Africa. The social and economic benefits of alternative systems for producing livestock, new methods of livestock transportation, and marketing will need to come under scrutiny.

The need is for an international research program on the ruminants embracing the three main ecological zones from the Sahara to the equator. Though production systems and their attendant problems vary from one ecological zone to another in Africa, research results obtained at one site should be applicable directly to others of similar ecological type. In the dry sub-Saharan regions more than elsewhere, heavy emphasis is needed on range management research. The intermediate region with a genuine tropical climate offers the technical possibility of using planted forage crops and pastures along with excess cereal grains and crop residues. In the Guinean rain forest region, the grazing of breeds that tolerate trypanosomiasis–Ndama and possibly others–among tree crops or on derived savanna can be considered. However, the dwarf breeds of cattle may never be economical to produce. Immunity to trypanosomes, implementation of tsetse fly control, or both offer the best promise for opening large areas of the humid tropics to cattle production where it is not yet feasible, and the use of Ndama or similar breeds should be considered a transitional system only. This region also offers some potential for short fattening or finishing periods for cattle from the rangelands, using grains and residues of industry. Cattle production systems, including zero grazing, may be needed to make maximum use of the vegetaion in each region.

To a major extent, nutrition and management research conducted with cattle will apply to sheep and goats. But there should be separate research facilities–particularly in East Africa and the humid tropics–dealing with the breeding, feeding and management problems of small ruminants.

Research to improve breeds of livestock, especially the cattle breeds, is much less likely to produce immediate benefits than research that would raise production through improved nutrition. The goals in cattle breeding are not only location or region specific, but the research itself is long-term in character and expensive. Thus, while a current goal in the humid tropics is to improve the Ndama breed, which is tolerant to trypanosomes but a poor producer of milk and meat, proper control of trypanosomiasis and other parasitic diseases would make this goal obsolete. In the highlands, breeding programs have consisted mainly in substituting European stock for local cattle since European stock do so well under that type of climate. Other programs in other geographical regions represent variations between these extremes. The long-range potentialities for range and tropical grassland improvement must be known, as must the outlook for disease control—especially with respect to trypanosomiasis—before livestock breeders can design programs of research that would have even the hope of satisfactory results. Meanwhile, establishing breeding programs will continue to be risky and breeders should be careful to analyze the long-term objectives that are most likely to succeed.

As is obvious from the above discussion, the most urgently needed research on animal disease concerns trypanosomiasis and East Coast fever. Although these diseases have been thoroughly studied over the past 50 years, at least, and can be reasonably held in check, the opportunities and challenges confronting scientists and the potential benefits to the cattle producers through additional research on these two diseases are sufficiently promising to encourage the African governments to expand their capabilities in this area of research. The scientific problem is to develop vaccines for a group of organisms, protozoa, which have as yet to yield to this technique on a field scale. The practical problem is to eliminate these two diseases as killing diseases of cattle.

The greatest need in trypanosomiasis research is to develop an effective vaccine for combatting trypanosomes in cattle and, in this connection, to understand the nature of the trypanosome tolerance capability of *Bos taurus Ndama* from Guinea and the Ivory Coast. Efforts to devise means of vector (fly) control more effective than those currently in use must also continue as a high-priority research aim. No single existing method of attack against the highly resilient organisms—fly and trypanosomes—is likely to wipe out the scourge of trypanosomiasis.

On foot-and-mouth disease, the main line of research should be to incorporate African strains among those against which vaccines are being developed and to field test vaccines in Africa.

The vaccines used against rinderpest are being constantly improved. Recently, an associated rinderpest-pleuropneumonia vaccine has been widely used in field operations in francophone countries.

Much of the research on contagious bovine pleuropneumonia should center on the refinement of diagnosis and on methods of immunization relevant to field applications—requirements that hold true for the diseases cysticercosis and streptothricosis. The better the human sanitary practices, the less cysticercosis occurs; but in the absence of adequate sanitation, research is needed to provide means of rapid diagnosis and treatment in the live animal, and development of an immunizing agent. A competent veterinary team, including a mycologist and a pathologist, is needed to do the necessary epidemiological work and to devise satisfactory methods for streptothricosis control.

Nonruminants With respect to nonruminant species–chickens and pigs–agricultural research must continue to look for ways to meet nutritional requirements, to breed types that can make better use of improved feed and are more resistant to insect pests and diseases and to heat stress.

The amino acid requirements for poultry and the protein–energy ratios for layers, growers and broilers, using locally grown feed are being investigated at Ibadan. Solutions to nutritional problems of this nature must receive top consideration, as must the control of poultry diseases including Newcastle disease, infectious bronchitis, Marek's disease, avian encephalomyelitis and fowl plague.

However, research in these areas alone is not sufficient to enable the African continent to achieve the target the FAO/IWP has set for a 10 percent per year increase in poultry and just under 6 percent in pigs. Additional research must be directed toward (1) increasing the production of feed grains and processing other crops efficiently so as to yield by-products that are useful as feed; (2) shifting from traditional to modern methods of management; (3) dressing, processing, preserving, transporting, storing and marketing of animals and animal products; and (4) economic management, taxation, and credit.

Research Capabilities

Ruminants One of the best evaluations of capabilities for research on rangelands and pastures was prepared under the aegis of the Ford Foundation (Robin and Brown, 1970) in support of the concept of building an international center for rangelands research and development in Africa south of the Sahara. For regional research in East Africa, the study points to the East African Agriculture and Forestry Research Organization (EAAFRO) and EAVRO. Some seven stations in Kenya, six in Tanzania, and eight in Uganda are concerned with problems of range management. The Serengeti Research Station in Tanzania, the Nuffield Unit of Tropical Animal Ecology in Uganda, and the Tsavo Research Center in Kenya are other important stations. Several projects in rangeland management and pasture improvement are being carried out at the University of Nairobi. FAO, under United Nations Development

Program (UNDP) financing, has a range management team operating in the Rift Valley of Kenya. Little rangeland research work is taking place in Somalia, in Zambia or Malawi, but in Botswana the Ministry of Agriculture, the Game Department and the Ministry of Commerce and Industry support such research.

With respect to livestock production and veterinary medicine, the IEMVT in francophone African countries and in Ethiopia operates and coordinates a network of stations and laboratories under the auspices of intergovernment cooperative agreements. The main laboratories in the network include the national laboratories for veterinary research at Dakar in Senegal; at Ndjamena, Chad; at Tananarive, the Malagasy Republic; at Niamey, Niger; and at Debre Zeit, Ethiopia. The main experimental stations are located in Ivory Coast (Bouaké), in Cameroon (Wakwa), and in the Malagasy Republic (Kianjosoa and Miadana).

One of the finest laboratories in Africa for basic research on animal diseases was built in the mid 1960's at Bamako, Mali, with major funding from the United States Agency for International Development (USAID). Never fully utilized, it now needs considerable modification and adjustment to be operationally effective. A number of stations devoted primarily to animal disease research were established under British auspices in anglophone countries. They are now nationalized and receive assistance not only from the United Kingdom, but from USAID, the Netherlands, Sweden and UNDP. These include such stations as the East African Veterinary Research Organization at Muguga, Kenya, and the veterinary research laboratories at Kabete, Kenya, and at Vos, Nigeria.

Special research laboratories–Nigerian Institute on Trypanosomiasis, Research (NITR) in Nigeria and the East African Trypanosomiasis Research Organization (EATRO) in Uganda–have been built to deal with problems that relate to trypanosomiasis, its control and the control of its vector the tsetse fly. At Ndjamena, Chad, and at Bobo-Dioulasso, Upper Volta, IEMVT has initiated a program of biological eradication of *Glossina* by liberating sterile males to compete with fertile ones in nature.

USAID in conjunction with the Agricultural Research Service (ARS) of the United States Department of Agriculture, and with the cooperation of the Government of Tanzania has been sponsoring field tests to evaluate the feasibility of employing sterile male tsetse flies to aid in the elimination of tsetse fly populations. Research workers with the International Atomic Energy Agency (IAEA/FAO) and other workers in the United Kingdom are investigating large-scale methods for rearing important species of tsetse flies, a necessary requirement for the application of this technique.

Capabilities for research on diseases other than East Coast fever and trypanosomiasis seem to be adequate. Research on foot-and-mouth disease takes place at the Wellcome Institute in Nairobi. World research on foot-and-mouth disease, including that at Wellcome Institute in Nairobi, Kenya, will eventually develop adequate vaccines, but an African research capacity must be developed for regional strain typing, specific strain vaccines and their application.

Rinderpest investigations are being handled through the campaign, Joint Project 15, of the Organization of African Unity/Scientific, Technical and Research Commission (OAU/STRC) under USAID and other donor support. The demonstrated effectiveness of available vaccines for the control of rinderpest and contagious bovine pleuropneumonia suggests that African capabilities are adequate for the research still required on those diseases.

For research on contagious bovine pleuropneumonia and for the production of the T-1 vaccine for its control, the veterinary laboratories of EAVRO, Kenya–and those at Vos, Nigeria; Ndjamena, Chad; and Dakar, Senegal–possess fine facilities and enjoy excellent reputations of accomplishment. There is a need for improved African research capacity, especially in the areas of personnel and equipment, for babesiosis, anaplasmosis, streptothricosis, cysticercosis and for diseases of nonruminants, wildlife and fish.

Nonruminants Centers engaged in research on swine and poultry include the animal science departments of many African universities; for example, Ibadan, Ife, Ahmadu Bello and Nsukka in Nigeria, Legon and Kumasi in Ghana, and those of many of the francophone countries. Ibadan researchers are inquiring into the amino acid balance and supplementation status of local feeds used as supplements for weaners and growers. They use artificial insemination techniques for improving local farmers' pigs in respect to growth rate and feed conversion efficiency, and study environmental factors on reproductive performance. Artificial insemination in pigs on a farm basis is considered inefficient and ineffective in the United States. Probably, in Africa, research resources should not be expended in this area. Introducing superior genetic characteristics through natural breeding programs is imperative.

WILDLIFE

Current Status of Production and Research

Wildlife–elephant, giraffe, the antelope species, for example–Africa's best known and most attractive resource, currently provides such great economic return to the countries of eastern Africa through the attraction of visitors who hunt and photograph it that its intrinsic value to agriculture is masked. But the wild species of ruminants have some special advantages over the domestic species. They can thrive on natural range too dry and too sparsely clothed with vegetation for domestic species because they require less water and are more resistant to disease in this environment. Consequently, they can be productively managed with domesticated stock in marginal agricultural and stock-raising areas or managed apart in areas where domestic species cannot thrive. However, unless these animals are wisely and economically managed as an integral component of the agriculture of the countries, they may survive only as curiosities in oversized parks and zoos. Or, because of overgrazing and impingement of domestic stock upon the land they occupy, certain species of wildlife may become endangered or even extinct.

Scarcely any scientific work on wild animals had been accomplished before 1950 according to Robin and Brown (1970). They further report a basic lack of information on past and present wild animal populations, habits, ranges, etc., but they recognize the great strides made by wildlife research in the 5-year period of 1965–1970, so that, in some respects, it is now in advance of parallel research on domestic stock. Many projects in Tanzania and Kenya, concerned with pasture trials, plant introductions, etc., do not neglect the fundamental problems of the interrelationships of wildlife and domestic stock. Little has been done on the large mammal species of the rangeland. The leopard, for example, is potentially one of the most valuable animals for its sporting value, pelt, and its reputed ability to control such pests as baboons and wild pigs. In terms of cash, one leopard may be worth three to six prime steers. The important birds and the insects of rangelands have not been adequately studied either.

Research Needs

The needs for research on wildlife as it bears upon the agriculture of the continent lie in five broad areas: (1) further documentation of the biology, physiology and pathology of the game species themselves; (2) study of their productive association with domesticated stock; (3) study of their place in patterns of the economic use of land; (4) estimates of their value when slaughtered for food, and (5) study of their interrelations with domestic stock with respect to diseases.

Research Capabilities

Such basic biological research as is conducted on wildlife species generally takes place in the game parks. The strongest center for this research in Africa is the Serengeti Research Institute with worldwide interest and importance beyond the borders of Tanzania where it is sited. The Nuffield Institute of Tropical Animal Ecology in Queen Elizabeth Park at Mwea and at Makerere University conducts a number of wildlife research studies in Uganda.

One of the institutions with capabilities for solving the problems of the potential threat to man from parasites he shares in common with wildlife is the Kenya Veterinary Laboratory at Kabete, Kenya, which has limited facilities for studying the life history and transmission of parasites. An expanded program in this field has been proposed, but the funds have not yet been available to permit it. Another institute in this field is the Tropeninstitut in Hamburg, Germany, which has programs in the taxonomy of parasites in game animals of eastern Africa.

A varied group of institutions handle the relationship of diseases of wildlife and domestic animals. The National Laboratory at Ndjamena operated by IEMVT has made systematic inventories of wildlife parasites and serological enquiries on ungulates from Chad and the Central African Republic. In the Central African Republic, a UNDP/FAO project is concerned with epizootic diseases in wildlife. EAVRO, Muguga, Kenya, is actively engaged in studies on East Coast fever and other *Theileria* organisms that may be pathogenic to livestock. The Kenya Veterinary Laboratory has conducted some studies concerned with possible transmission of domestic livestock parasites to wildlife and would like to expand this program. The Wellcome Laboratory for Experimental Parasitology in Nairobi, Kenya, has a program on foot-and-mouth disease, and the Animal Health Center in Kampala, Uganda, has done some work on tuberculosis in African buffalo.

Fish

The potential of African fresh waters to provide fish protein and water for irrigation and other human needs is especially germane to this study. Fisheries in the man-made lakes impounded behind such dams as the Akosambo on the Volta, the Kainji on the Niger, and the Kariba on the Zambesi also come squarely within the Committee's terms of reference. However, the fishing industry based on exploitation of coastal saline and brackish waters and on the fish catch *per se* from the natural fresh waters of the continent falls outside the purview of this particular study.

Current Status of Production and Research

Thousands of fish ponds were dug in west African countries in the 1950's, but for obscure reasons they never became productive. Experimental fish ponds built at the agricultural experiment station near

Salisbury in Rhodesia and on the Keyberg station near Lubumbashi in Zaire have not multiplied beyond the confines of the experiment station; yet fish indigenous to the fresh waters of the continent, especially species of *Tilapia*, readily respond to cultural methods. They thrive in warm water, feed on a variety of plant materials, spawn the year round, are very prolific, and are adaptable to changes in environment, which includes the presence of other kinds of fish. Typical farm pond management will give yields of 1,000 kg per hectare while expert management will bring yields up to 5,000 kg per hectare per year.

Research Needs

The first research need is to ascertain why the people of Africa have not accepted fish pond culture. Once this information is available, research could then move toward the control of water quality and water level compatible with maximum fish production, development of adequate food for fish in fish ponds, and control of fish diseases. The lack of individuals technically trained for research in the disciplines important to an understanding of production under fish pond conditions may explain in part why fish culture in Africa has not taken hold. Even more important is the building of interdisciplinary teams to work together to establish appropriate environments for such pond culture. Veterinarians, fish biologists, and engineers need to operate as research teams to establish requirements and to demonstrate potentialities for production in specific areas and at costs that the market will justify.

Research Capabilities

A number of African countries sponsor active fish culture programs. Notable among these are the Central African Republic, Cameroon, Ghana, Nigeria, Ivory Coast, Republic of South Africa, Rhodesia and Uganda. In addition, those countries–Ghana, Nigeria, Zambia, for example–where large dams have recently been built and where new man-made lakes have come into existence may offer special opportunities for thorough studies of stocking and maintaining freshwater fisheries.

CONCLUSIONS AND RECOMMENDATIONS

In 1968 a group of specialists on East African range problems met to consider comprehensive research efforts that could be implemented in that area. Out of this and subsequent meetings grew a concept that the 30–35 main livestock and rangeland improvement stations for the entire continent should be woven into a network supported and financed from a compact, central administrative headquarters located in East Africa. In succeeding years this concept changed to one that would develop one or two strong animal production research centers, one to be sited in East Africa and another in West Africa. At least two task forces canvassed the livestock growing areas of Africa for information and advice on establishing such international centers with appropriate associated stations keyed to the national centers and their objectives. However, the problems of research on livestock improvement are diffuse, and it continued to be difficult to reach a decision on organizing strong, well-defined centers of livestock research on the continent. In 1972, a third task force established under the aegis of the World Bank (International Bank for Reconstruction and Development) reviewed the needs and opportunities for designing appropriate research centers for investigations on animal production in Africa. This task force recommended that one central livestock production research center be built with its headquarters in Addis Ababa, Ethiopia. The Technical Advisory Committee of the Consultative Group on International Agricultural Research (CGIAR) and the CGIAR African Livestock Subcommittee endorsed the concept of the International Livestock Center for Africa (ILCA) with its central laboratories in Addis Ababa, and the International Development Research Center (IDRC) of Canada has since become the executing agency for ILCA.

•*Because of the present extremely low rate of livestock production in Africa and the consequent need and opportunity for betterment of it, the Committee recommends that through the development of ILCA, and in other ways as well, CGIAR and African governments intensify their present efforts to build strong programs of research on livestock production to encourage a higher rate of livestock production, to raise the amount and quality of protein in people's diets in Africa, and to anticipate the time when livestock will become an increasing source of foreign exchange earnings.*

While husbandry, nutrition, and range management as integral parts of animal production investigations have been difficult areas in which to build unified research efforts, animal disease as an important component has traditionally led to successful international research efforts. The CGIAR agencies, together with a number of African countries, investigated the possibilities of building in East Africa an International Laboratory for Research on Animal Diseases (ILRAD). This laboratory will complement and supplement existing laboratories in Africa dealing with these problems and will focus on immunological techniques, and particularly the development of vaccines for the control of East Coast fever and trypanosomiasis.

• Research on immunology as a means for controlling East Coast fever and trypanosomiasis is of the highest priority and *the Committee recommends that donor agencies and governments continue to seek all possible ways to bring the best scientific talent, from Africa and from elsewhere, to bear on establishing the appropriate institutional structure and marshalling the best scientific acumen to develop vaccines to control East Coast fever and trypanosomiasis, primarily.* One key effort in this regard is the establishment in Nairobi, Kenya, of the International Laboratory for Research on Animal Diseases (ILRAD). (See "International Agricultural Research Institutions," Chapter XVIII).

Research on wildlife has been subject to the push and pull of extremists who, on the one hand, would shoot wild animals for food and for sport regardless of long-term consequences including possible extinction of species and, on the other, would misconstrue the concept of the balance-of-nature and save animals for posterity at any cost.

The need is for an institute or a program that could operate from an objective research base. One appropriate ecological area for such an institute might be the Serengeti Park of Tanzania. However, game animal research is often location specific, and outreach programs would be necessary to bolster the central research program.

Research on wildlife as it relates directly to the agricultural sector of the economies of the African nations should consist of fundamental studies on (1) characteristics of game animals that enable them to thrive in areas where domesticated stock do not prosper; (2) wise use of land resources over which game animals range, taking into consideration the socioeconomic conditions of the people in these areas; and (3) systems for cropping or harvesting game to provide food for human consumption. Existing research capabilities on African wildlife need to interrelate better than they do at present with those on livestock, particularly with respect to land use and the diseases common to both groups.

Few African research workers at present give attention to wildlife, and few, if any, expatriates work on a sustained basis in Africa toward rational management of this unique resource; therefore, training men for these sorts of investigations is a priority matter. Game wardens are being trained in Tanzania and in Cameroon. IEMVT has developed a training scheme in ecological science for wildlife research workers. But these kinds of programs ought to be expanded and should embrace preparation of qualified research workers for collecting the basic data so essential to sound decisions on the utilization and management of wildlife.

XIV

Pests and Pathogens

This chapter presents an overview of the pest and pathogen situation and draws attention mainly to those that are not host-specific, i.e., cannot be assigned to any one special plant or animal. It points to three problems which are continental in scope: (1) acquiring a base of information concerning many pests and pathogens; (2) formulating and implementing quarantines that admit interchange of plant and animal stock but protect the public against the onslaught of new diseases; and (3) designing and implementing regulatory procedures for the use of chemicals essential to the control of target pests and pathogens, but potentially harmful to man and the environment.

Rats, birds, insects, nematodes, fungi, bacteria and viruses comprise the "pests and pathogens" under review here. In the chapters on commodities–including the one on livestock–the role of specific pests and diseases in damaging commodities is woven into the accounts of the current status of research, the needs, and the capabilities for research. Research on pests and pathogens that have specific host preferences interrelate with the cultural practices, the breeding methods and other techniques designed to increase crop and animal production.

RODENTS

Loss and damage from rats can be quite diverse. From Liberia comes the report that rodents consumed at least 100,000 tons of the rice harvest expected in one year. Rodents consumed newly planted seeds and cut young sprouts of early sown food and cash crops in southern Nigeria, causing 50 percent loss on several thousands of hectares. In Sierra Leone, four out of five newly transplanted seedlings of rubber trees were destroyed and planting had to be repeated seven times. In a Rhodesian sugarcane scheme, one crop year ended with a massive invasion of rats, which drowned in such numbers that they blocked the irrigation channels—even though the rats were being removed from irrigation plots or ditches at the rate of one ton per day. All this in addition to damage to canal banks by burrowing.

Rodents, singly or as a group, have received less research effort than other pests, despite the fact that many species—some native, others introduced—cause serious depredations in Africa. A number of surveys have been conducted, however, and the importance of rats as pests has been delineated. Two introduced species *Rattus rattus* and *Rattus norvegicus* are widely distributed as pests of foodstuffs in storage. Among the many indigenous species the multimammate rat *Rattus natalensis*, which inhabits equatorial and tropical Africa, has become dependent in a major way on man for food and shelter, though it also lives in large numbers away from his dwellings and field crops. The savanna rat *Arvicanthis niloticus* living in the Sahelian and Sudanian zones of Africa, causes great damage to growing crops, especially rice, as does the giant or pouched rat *Cricetomys gambianus*, which creates its burrows in towns and villages where it lives by scavenging and takes a considerable toll when it has access to stored food.

Africa has virtually no capabilities for rodent research at the present time, but interest in investigating problems of rodent damage is developing. Tanzania considered it serious enough to offer to host a biology and control training course in 1970 under the World Health Organization (WHO) Danish program in order to prepare personnel of their own country and of neighboring East Africa to cope with the rodent problem.

Little is known of the ecological reasons for sudden explosions of rodent populations in the field or in their demise during most years, and it is not known if strains of crops resistant to rodent attack exist. These research gaps and others seem to be widespread throughout Africa, and a concerted effort needs to be developed to meet this new challenge. Governments and international agencies need to build long-term research programs to tackle the rodent problem systematically in the same way that the study of insect pests is now being conducted. Such research needs to be focused on the acquisition of knowledge that would lead to the development of practical and economic control measures to combat these vertebrate pests. Finally, since no research institution is pre-eminent in this field at present, priority should be given to identifying an existing institution that would build a regional capability in rodent research and control in Africa.

BIRDS

Birds, especially the weaver bird *Quelea quelea*, devastate the cereal crops in the dry savannas of Africa. (See Research Needs, "Sorghum," Chapter IV). In fact, the availability of sorghum, rice, and the millets as basic cereals for the rising populations in semiarid parts of Africa will depend to a large extent on what happens to the vast clouds of these brightly colored sparrow-sized birds, which flock to the fields and feed on maturing grain when it reaches the "milky stage". In some areas these pests have already caused farmers, even in ecologically unsuitable areas, to substitute maize or cassava, which the birds do not attack readily, for the traditional sorghum and millets. So damaging have these birds become that governments have appointed bird control officers to try to exterminate them. Application of pesticides from the air has been partially effective but dangerous; the technique mentioned earlier of blasting nesting sites has proved helpful but not conclusive. In the blasting procedure, government scouts locate nesting colonies suitable for extermination; that is, those among trees in and about sorghum fields. The bird control officer then strategically arranges approximately ten 150-litre (40-gallon) drums filled with gasoline over an area of about an acre and explodes them by means of a gelignite charge coupled with an instantaneous fuse. Approximately 200 million birds were thus destroyed during the 1961 season in the northern part of Nigeria; yet the quelea presents the same problem to farmers today as it has over the past 10 years.

Sophisticated, devious, and subtle control measures are supplanting the explosive techniques. Bearded millet, allegedly resistant to quelea, is available and can be planted to curb the damage these birds cause. Sorghum varieties with goose-necked heads, large glumes to cover the seed, large barbs on the glumes, and grains reddish in color and rich in tannin causing them to be distasteful to the birds are available. But even if most farmers planted these varieties, and they do not, such varieties might not be effective when planted over extensive areas.

Additional research should be encouraged on the biology, ecology and behavior of weaver birds, on tree populations, on nesting sites and on the importance of water and irrigation systems as they affect bird population. To what extent further research should be conducted on breeding sorghum varieties tolerant of depredations from quelea is a moot question. Some of the same characteristics of sorghum grains that appeal to birds–absence of bitterness and low tannin content in the grain, for example–are those that contribute to high quality sorghums for man.

Various research centers in Africa have studied the biology and reproduction of quelea. As mentioned earlier, the Organisation Commune de Lutte Antiacridienne et de Lutte Antiaviaire (OCLALAV), a West African organization, has stimulated research on these pests. The East African Agriculture and Forestry Research Organization (EAAFRO) has supported research on breeding sorghum resistant to bird attack, and the Tropical Pesticides Research Institute at Arusha, Tanzania, in collaboration with the London-based Centre for Overseas Pest Research, has conducted some basic research on the breeding biology and migration patterns of quelea.

NEMATODES

Damage by nematodes has been underestimated. These organisms, latent destroyers under shifting cultivation or other existing crop rotational systems, become devastating especially to horticultural crops as intensive one-crop farming systems replace shifting cultivation. One would hope that the value of produce from horticultural crops on a per acre basis will soon admit the use of costly modern techniques to control nematodes. In any case, the study and the control of nematodes should be expanded.

The whole nematode population, including free living as well as parasitic forms, has been thoroughly surveyed over the past 10 years in Nigeria in a program at Moor Plantation cooperatively supported by the government of Nigeria, USAID, USDA, and The Rockefeller Foundation. Recently IITA has initiated a search for plants (cowpea, maize, sweet potato, yam, etc.) resistant to nematode attack (See Chapters IV, V and VI). In francophone Africa, studies of these worms have centered mainly on the damage they cause in cleared savanna formerly forested. Recently, ORSTOM launched a research program on nematodes of the savanna zone from its station at Dakar.

The importance of nematode damage to the tea plant, especially to young plants in nurseries, has long been recognized. At the tea research institutes in Malawi and Kenya, nematodes of the genus *Meloidogne* were very early recognized as major pests and were studied intensively with the consequent development of cultural methods to avoid their depredations.

The most immediate problems are to intensify research on those nematodes that attack plants at the nursery stage, as well as on those that attack horticultural crops under field conditions; to devise cultural methods where feasible to combat these pests; to develop pesticide regimes which would control nematode populations without harmful effects to crops or the environment; and to design novel methods of nematode control where methods currently in vogue are neither practical nor economic.

INSECTS, FUNGI, BACTERIA AND VIRUSES

Some of the finest research in the world on insect pests and on the bacterial and viral pathogens of crops and livestock has taken place in Africa. Migratory locusts, for example, can now be contained at their breeding sites; armyworms can also be held in check. Varieties of maize are available that resist host specific rust for the time being and, until recently, varieties of cassava resistant to the several cassava viruses were also available. Brown ticks (a vector of East Coast fever on cattle) and tsetse flies (the transmitting agent for cattle trypanosomiasis) yield to chemical and other control, but these organisms constitute dynamic populations challenging man's ingenious attempts to hold them at bay.

Substantial resources have already been tapped for basic biological studies on selected pathogens, e.g., coffee berry disease in Central Africa and black pod rot of cocoa in West Africa. In many cases, however, not enough is known about the biology, ecology and behavioral patterns of these pathogens to design anything more than temporary control measures.

The dozens upon dozens of insect species, which operate either as pests of crops and livestock in their own right or as vectors of disease, have been the subjects of more biological and ecological research than have noxious species of rodents and birds in Africa. The historical trend of such research has followed that of other parts of the world. African entomological research passed through periods of strong emphasis on manipulation of the environment during the 1920's and 1930's, then to exploitation of chemicals during the 1940's and 1950's, and finally to the current fashion of studies on physiology and ecology.

Centers of plant and animal protection have developed rather evenly over Africa. In Nigeria at the University of Ibadan, at Ahmadu Bello University and at IITA, entomology and plant pathology are well-established. The East African Community has supported research on forest insect pests and on armyworms at EAAFRO and, aided by the United Nations Development Program and the Canadian International Development Agency (CIDA), on ticks and tsetse flies at the East African Veterinary Research Organization and the East African Trypanosomiasis Research Organization.

The new International Centre of Insect Physiology and Ecology (ICIPE) based at Nairobi, Kenya, draws talent and financial backing from many countries of Africa, from Europe, from Japan and from North America for its research programs on aspects of the biology of tsetse flies, armyworms, termites and ticks (see "International Agricultural Research Institutions," Chapter XVIII). At the University of Nairobi, the only department of entomology in mid-Africa is now well-established with a strong postgraduate research program in problems of tropical agriculture (animal-biting flies, termites, locusts, plant bugs, nematodes, etc.). In Uganda, some of the best research on cotton pests and stem borers is being done at the Kawanda and Serere research stations. The National Council for Scientific Research in Lusaka, Zambia, is now engaged in some excellent ecological research on tsetse flies. In the francophone zone, entomological studies are undertaken by the universities of Abidjan, Dakar, Brazzaville and Tananarive; in the research centers of ORSTOM at Abidjan, Ivory Coast, and Brazzaville, Congo; at Organisme de Coordination et de Coopération pour la lutte Contre les Grandes Endémics (OCCGE) at Bobo-Dioulasso, Upper Volta, in liaison with ORSTOM; and by IEMVT at Dakar, Senegal, at Ndjamena, Chad, and at Bobo-Dioulasso.

Proposals to form strategically located plant nurseries to monitor the most dangerous of the insect pests and plant pathogens of Africa's economic crops are currently being considered; they would answer an important need. Natural sites already exist that would serve as proving grounds for testing collections of the world germ plasm against these pests and pathogens. The Kenya highlands, for example, harbor most of the virulent strains of black stem rust of wheat; world collections of wheat planted there undergo as severe a challenge as anywhere in the world. Cowpeas seem subject to the full range of pests and diseases in the vicinity of Ibadan where the University of Ibadan and IITA are situated. Other areas could furnish opportunity for severe tests. The Kigesi region of western Uganda, for example, has the appropriate climate to provide a severe field test for resistance of potato to late blight, though it may never compare with the Toluca Valley in the mountains of central Mexico, which harbors all races of the fungus causing late blight (including the sexual phase, which permits new variation).

QUARANTINE

The demands of farmer, pastoralist and consumer have greatly accelerated research by plant breeders throughout Africa. An acute need for modern quarantine facilities and expertise emerges from this search for improved plant stock. As a result, plant quarantine services—which seldom have staff, money and physical plant to cope as well as they would wish with the normal flow of plant materials—have an overwhelming service load. Problems arise with both the import and export of seeds and vegetative materials from plant-breeding centers; these problems will become more serious as such organizations as IITA and the West African Rice Development Association (WARDA) begin to release materials for area-wide testing or arrange for their multiplication and distribution.

Research on quarantine procedures is needed that will lead to a quicker, surer means of verifying that plant materials are free from diseases and pests, and to means by which genetic stock from this material can be introduced and made available to plant breeders, even in the presence of such diseases and pests. More frequent surveys of disease and pest incidence are necessary to determine how rigorous restrictions upon the import of particular sorts of seeds and plant materials need to be.

Movement of livestock across national boundaries poses problems similar to those with plant materials. It is not always possible for livestock to be certified as to the pathogens it may carry from its point of origin. The recipient country must insist therefore upon having the capabilities to check the purity and identity of such imports and any pathogens they may contain. In some cases it may even be necessary to import virulent pathogens for scientific purposes. Even this can be done, provided such pathogens are processed, transported, used and stored in secure facilities by fully competent people to the satisfaction of participating governments.

Scientists and government personnel need to recognize what quarantines can and cannot do. At best, they can only slow down the ultimate spreading of the range of pests and pathogens, not prevent it for indefinite periods. Not all restrictions have biological bases; cumbersome administrative procedures often cause delays, losses, and barriers to imports. Streamlining plant quarantine and introduction procedures is essential if African farmers and consumers are to benefit quickly and fully from the output of new materials from the plant breeders' laboratories and field experimental plots.

National governments have the responsibility to set and to administer quarantines, but it is important that the quarantines should be the common concern of the research workers and members of technical services as well as of the quarantine staff, so that both the nature of the problem and the appropriate quarantine procedures are established and developed by agreement and do not become a matter of potentially hostile confrontation. The necessary consultation could readily be developed under the auspices of the Economic Commission for Africa (ECA) and the Food and Agriculture Organization of the United Nations with cooperation from the Consultative Group on International Agricultural Research (CGIAR) to consider the benefits to be derived from

1. establishing third-country quarantine stations through which plant and animal materials could be passed, where the danger of introducing new pests and pathogens would be minimal;
2. building regional quarantine stations in several localities of Africa in which individual nations would participate; and
3. improving communication and cooperation between individual country quarantine stations and the research institutions operative in those countries.

An FAO-sponsored quarantine station is now being activated at Moor Planation, Ibadan, Nigeria.

PESTICIDES

The total area to which pesticides are applied in Africa is certain to expand rapidly, despite the novel control measures coming into use as alternatives to chemicals that are noxious to beneficial organisms in the environment. Traditionally, land planted to cotton, cocoa, tobacco and other so-called plantation crops having capital backing and produced mainly for export has received a heavy pesticide load. The use of pesticides on these lands is not subsiding. General feeders, locusts and armyworms, are still held in check through the use of pesticides. As tomatoes and potatoes become intensively cultivated and their value per hectare rises, farmers will apply pesticides to protect them. Even the grains (maize, perhaps) and the grain legumes (certainly cowpeas) may need and receive pesticide applications. Among the animal pests, tsetse flies have been responsible for widespread indiscriminate pesticide applications in years past. Pesticides appropriately used still constitute mainstay methods for their control, notwithstanding the advent of alternative methods under experimentation, such as the male-sterile technique of reducing fly populations below economically damaging levels. Monitoring pesticide usage is absolutely essential for safeguarding the public. Abuses and malpractices leading to the restriction and prohibition of the use of hazardous pesticides in developed countries may make it uneconomic for industry to continue to manufacture them. This will limit the availability of badly-needed pesticides in other countries, among them developing ones. At another extreme, inadequate pesticide regulations in developing countries expose these countries to the sale of pesticides that are improperly labeled and inadequately controlled.

Investigations of uses and abuses of pesticides should lead to wise legislation and enactment of proper laws to protect growers and consumers in all countries. An informal canvas conducted in late 1971 (Starnes, 1972) of ten African countries revealed that only six of them had pesticide laws, all enacted in 1970 or later; none was implementing clauses requiring registration and labeling; none had in operation a laboratory performing quality control of commercial pesticides; none indicated that the application of pesticides by aircraft was being regulated; none had an operational laboratory monitoring pesticide residues on food products; none had an interdepartmental agency dealing with pesticides and the environment; none considered that pesticides constituted a serious environmental hazard; and the response was "no" to the question—"Do you consider that your country has adequate machinery to cope with the problem of pesticides in the environment?"

FAO and WHO, among other international agencies, have been advising developing countries on regulatory procedures in the use of pesticides. FAO, in fact, organized a working party on pesticide residues and issued suggestions for the establishment of pesticide control organizations. More than advice is needed.

Legislation and enforcement of regulatory practices on the sale and use of pesticides must stem from (1) adequate survey and taxonomic work and knowledge of new means for controlling, selectively, major pests upon a crop in a system where up to four crops may be interplanted and when both pest and host plant may be present throughout the year; (2) new ways to inform peasant farmers how to use and store pesticides safely, when no more than about 10 percent may be literate in the language in which the labels are written; and (3) methods for correcting the widely held view that some of these chemicals—DDT and BHC, for example—can safely be mixed with feed stocks of cereal grain to protect them against stored product pests.

CONCLUSIONS AND RECOMMENDATIONS

Research on the biology, behavior and ecology of the leading pests and pathogens of Africa's crop and livestock resources becomes urgent as agronomic practices improve and new and improved varieties make crop and animal protection profitable. Rats are becoming increasingly important as surpluses develop and the need to store crop and livestock produce increases. Species of birds (*Quelea quelea*) may continue to ravage field crops in the savanna areas of Africa, depending on the evolving pattern of field crop husbandry in the area. The nematodes are also certain to increase in importance as more intensive or even continuous cropping replaces shifting cultivation, especially if susceptible crops are grown frequently.

Intensive work on rats, birds and nematodes may need to be done at a few places only, since the broad outlines of the biology of these pests may be constant over large areas of the continent. Because we know so little about the biology and population dynamics of birds, rats and nematodes, a great deal of research will need to be done at these places to develop control measures. The chemical control of rats and birds may always present real dangers to human beings and livestock because, in their physiological and biochemical makeup, these pests are more like human beings than are the insect pests and plant pathogens.

The insects and plant pathogens (fungi, bacteria, viruses) have many more location-specific features with respect to dispersal and survival than do birds, rats and nematodes; insect and plant pathogens may need study in detail at many more centers. While Africa and other continents share a common population of pest and disease agents, much basic research still remains to be done on those pests peculiar to Africa. On those species that are host-specific, much of the basic research must continue to be conducted in conjunction with agronomic, breeding and other investigations that relate directly to the improvement of the host. Concentrated international efforts will need to continue, especially on some of the general feeders like locusts and armyworms.

Two outstanding problems, not themselves of a research nature but entirely relevant to establishing and implementing research programs, are (1) plant and animal quarantine based on biological realities and (2) safeguarding the public through regulation of the sale and use of agricultural chemicals and the training of men and women in the proper use of crop and animal protective materials.

- On quarantine, *the Committee recommends that an international team of government administrators and scientists be formed, possibly under the aegis of ECA and OAU, to analyze the problem of quarantines thoroughly, and to make specific recommendations as to how the existing quarantine systems can be improved and, if necessary, new or alternative ones created.* The Committee recognizes that national governments must take the ultimate responsibility for setting appropriate regulations and building adequate facilities. In developing such regulations and facilities, greatly increased participation of international organizations already involved—FAO, UNDP, ECA, OAU, for example—would help.
- On protective materials, *the Committee recommends that governments examine closely the need to enact suitable laws to deal adequately with the problems of pesticide standardization, active ingredients, effec-*

tive but safe formulations, warnings on hazards, monitoring environmental pollution, and correct usage. Inevitably African farmers will feel an increasing need to use agricultural chemicals whether or not they may be hazardous. Ideally, then, these chemicals should be solely in the hands of professional plant and animal protectionists trained to handle them, to operate the application equipment, and to decide upon the timeliness and dosages required in their use.

XV

Systems Studies

In Chapter II, the Committee considered specific crops and their research needs by placing them in the context of various biological, environmental and social systems. That theme is reintroduced here because it is one of the more important concepts to be applied in agricultural development during the present decade and beyond. Implementation of system studies will bring together the production specialist and the economist, for example, each to pool his knowledge in an understanding of existing farming systems and how to improve them.

Systems studies seek to determine the most effective ways of utilizing the resources of a community for its own development. They have important contributions to make to the widespread problems of determining the sort of technical advances that are needed and can be used by farm people, and why so many advances produced by agricultural scientists are of no interest to the people they are intended to benefit. Such studies are a normal corollary of the package of practices growing out of the experience of the Green Revolution. They take into account all relevant variables and seek to order them in logical fashion to bring about agricultural improvement in the most efficient and timely way.

Systems theory derives from the perception that a system such as a food-crop plant, or a farm enterprise that grows various crops at different times, or a factory, or a national economy, cannot be understood unless it is considered as a functioning whole as well as analyzed in its parts. The approach considers that systems that are completely different often have features in common that can be studied as properties of systems. In the words of one of the field's pioneers, "systems theory is a broad view which far transcends technological problems and demands, a reorientation that has become necessary in science in general and in the gamut of disciplines from physics and biology to the behavioral and social sciences and to philosophy" (vonBectalanffy, 1968, p. vii).

Systems studies, as the Committee views them, are intended to define the areas and ways in which new technology can help most effectively to improve the design and operation of more productive systems of resources used by rural people in the humid tropics. In this way, they help to define the objectives of research as well as to put them to work.

The International Institute of Tropical Agriculture defines its purpose in this area as *the pursuit of integrated, interdisciplinary research toward the development of new farming systems for the lowland, humid tropics.* Physical, biological and socioeconomic factors that bear on a farm or rural community fall within the scope of this approach. Under the IITA plan, agricultural engineers deal with energy (including labor) bottlenecks that limit smallholders' productivity. Agricultural economists assess the various factors in the decision-making process of small-scale farmers and examine proposed production practices in terms of markets, prices, costs and availability of commodities. Physical concerns include pedology and soil management; soil fertility; the physics, chemistry and microbiology of soils; soil and water engineering and agrometeorology as they relate to crop growth and the maintenance of fertility; and organic matter content and physical structuring of the soil to prevent erosion and maintain sustained high levels of productivity of annual crops. Biological factors include the improved technology coming from crop improvement and protection programs; the possible usefulness of soil-conserving crops; diversification of crops; multiple cropping in rotation plans; and changes in disease, insect and nematode populations and weed patterns under different crop combinations.

In systems studies, complex algebraic and arithmetical methods of analysis, facilitated by using a computer, make it possible to determine which of the many theoretically possible systems should actually be tested in the field. They also make it possible to estimate the size of the effects and interactions of specific factors in these complex systems, whose action cannot readily be determined by direct measurement.

REQUIREMENTS FOR SYSTEMS STUDIES IN AFRICA

Effective systems studies require reliable, relevant and sufficient basic data, appropriate theoretical concepts, competent personnel and adequate computing facilities.

Data

Few African countries have sufficient data on areas, yields, or even the prices of inputs and products; some need more data even on such essential determinants as weather and disease. Without these data, reliable secondary measurements of agricultural productivity and economic activity–such as national income, expenditures, price indexes and marketing margins–cannot be developed. Lack of primary and secondary descriptive information restricts research on agricultural development projects, programs and policies. Both national and donor agencies usually underestimate the money and manpower needed to collect and process these data.

Agricultural systems, particularly those that use advanced technology, tend to be closely adapted to the environment. They are locale-specific. The data needed to model these systems must reflect this specificity. Similarly, the data needed for studies of regional or national systems must take account of the diversity of prices, production methods, resources, demographic conditions and institutions.

In short, the data must be obtained in Africa mainly by African agencies. Research and training centers will require staff and facilities to collect primary data for their own research as well as to extend and help validate information gathered by official agencies. An example of such a compilation of data can be found in the Department of Agricultural Economics, Ahmadu Bello University, Nigeria, which has worked for almost six years to describe the agricultural situation in the north of Nigeria from a socioeconomic perspective at the level of the village farmer.

Theory

The study of agricultural systems must be able to use information from the whole gamut of disciplines in both the natural and the human sciences that will help the understanding of how agricultural systems work; much of this understanding is expressed in theory and, though the application of theory and the data to which it is applied are locale-specific, much of the theory itself is general. Hence scientists working in African agricultural systems can, at least in the early stages, borrow or adapt from the experience of developed countries much of the theory and many of the models and submodels that are needed. As they test these theories rigorously against African realities, they will develop the theory and improve the models.

Cooperative research on African agricultural systems involving foreign, as well as local, agricultural institutions can also be extremely productive. In response to a request from USAID for the services of an outside agency to assist in obtaining an objective assessment of the rural development program in Nigeria and to carry out investigations to improve that program, the Consortium for the Study of Nigerian Rural Development was organized in 1964. It had seven members: Colorado State University, Kansas State University, Michigan State University, University of Wisconsin (Madison, Wisconsin), Research Triangle Institute, USDA, and the United States Department of Interior. In 1968, the Consortium, with the cooperation of the Nigerian government, concluded a thorough study of the agricultural sector of the Nigerian economy (Johnson *et al.*, 1969); this study has served as a model for succeeding internal analyses, which the Nigerian government is currently undertaking.

Personnel

Several African agricultural economists use systems methods and are beginning to modify existing theories and models to suit the real conditions of Africa. As objective methods of forming and monitoring agricultural policies become more widely used, more and more systems scientists will be needed. They should include people originally trained in applied natural science and agricultural technology as well as in agricultural economics, statistics and mathematics. This range of backgrounds is essential since the field is, above all, a multidisciplinary one in which natural phenomena, the results of controlled experiments and trials, and technical factors are at least as important as economic and social data and concepts.

Little serious recognition has been given to the importance of the human element in all agricultural research; social and cultural investigations must accompany technical experimentation in order to develop innovative practices that farmers will wish to and be able to implement efficiently and effectively. The professional separation of technologists from economists and of training from research, which is usual in so many of the developed countries, could seriously impede practical progress in Africa.

In many cases, agricultural faculties in universities are now recognizing the importance of genuine multidisciplinary research and, accordingly, some are taking steps to remove the entrenched traditions of academic individualism and departmental independence that work against an integrated systems approach. Sociologists, political scientists and anthropologists have much to contribute. Multidisciplinary research institutes, such as IITA or the Institute of Agricultural Research at Ahmadu Bello University, may offer fruitful environments for agricultural systems research. It is important to provide sufficient training openings at these centers for programmers and other intermediate-level and professional practitioners as well as for research workers.

Computers

If the kernel of systems theory is a reorientation away from narrow views to a broad one, systems research clearly can make use of many approaches, some of which may demand no special materials and others of which may require extremely complex equipment. However, as more and better data and theories become available to an increasing body of workers, systems analysts must rely increasingly on computers to build elaborate mathematical models of such complex systems as national economies and to test the effects of changes in one or more components in a system.

Because computers are costly and must be appropriately housed and competently maintained, it seems wise at this stage to encourage a few (perhaps not more than two in each of the main ecological regions) strong and truly interdisciplinary institutions in Africa to be provided with such equipment and to be responsible for its maintenance and the updating of data.

CONCLUSIONS AND RECOMMENDATIONS

Systems analysis has an important role to play in developing an overall approach to rural development, but it must be employed with discretion. Very often much the same results can be achieved at lower cost with less sophisticated methodology. Given a shortage of basic data and the problem of evolving suitable models, many partial solutions can be derived without such complex procedures. Researchers should not lose sight of the fact that one of their roles is to provide solutions to human problems and this may often be done using methodology that is less than ideal, but more appropriate, given the circumstances.

The need exists for socioeconomic field research to learn about the bottlenecks to increasing production and income, and this need should be stressed. This research must be done by the institutions of the countries concerned. External agencies, however, can provide support and some technical assistance; they must realize that this type of research is long-term and has to be sustained over a period of years, so any support must be long-term. This is especially true when dealing with such questions as rate of technological change and the impact of technological change in a particular region. It takes time to assess the impact of change and to analyze the factors for or against the acceptance of change.

• *The Committee recommends that IITA be encouraged to pursue the approach it has developed to the study of farming systems and that such studies be inaugurated for the other principal ecological zones of Africa.* An approach similar to that of the studies of agronomic systems is needed with livestock and range management systems.

XVI

Science Policy for Agriculture

A science policy for agriculture is a definite course of action adopted and pursued by a government to utilize science to achieve prescribed goals. The first step is to set the goals and these must mesh with other national goals. Next, the implications for formulating, coordinating, executing, and evaluating policies directed toward the prescribed goals must be ascertained–i.e., how each of these processes is to be carried on most effectively with limited resources, what the problems are, and how they can best be solved.

The science policy of a government must be concerned with (1) storing, retrieving and disseminating information; (2) research and development; (3) education and training; and (4) institutions that serve all these purposes (how to associate them with the political and development purposes of government). Ideally these components should be consciously articulated together; in practice, more often than not, they evolve separately.

A nation's library holdings are often divided among universities, research institutions and government departments (only in Nigeria is there a union list of agricultural periodicals), and relevant information about human population, health and nutrition, economic trends, and meteorology are held in separate government offices.

Usually agricultural research is carried out by the Ministry of Agriculture; sometimes it is done by other ministries (the Ministry of Co-operatives, the Ministry of Rural Development, for example), by universities, by unofficial research and/or development organizations; and sometimes research is controlled from abroad, and/or by commercial firms. This research is seldom explicitly linked with other pure or applied work in biology, nutrition, weather and climate, economics, sociology and other disciplines relevant to agricultural and rural development.

Responsibility for educating and training manpower is often divided between the Ministry of Agriculture and the Ministry of Education, and universities may be largely autonomous in their decisions concerning different subjects related to agricultural development.

A number of individual nations may not be able to maintain the full range of elements of science policy listed above. Moreover, whatever the size or prosperity of the nation, the organization needed to gear science effectively to national goals may seem dauntingly complex. No nation, however, can afford to waste time and resources by allowing its policies for agricultural science to develop haphazardly.

FORMING SCIENCE POLICY FOR AGRICULTURE

History, present circumstances, and traditional administrative style affect agricultural science policy variably, i.e., the organization and history of different African countries might call for different policy patterns. However, the center of that policy for each country might well be an advisory and consultative body to the cabinet—here designated as Agricultural Science Council (ASC)—which specifies the scientific needs and consequences of the agricultural development policy formed by government. This body might not have full authority to determine the development of policy, but it is essential that it help to do so. It would bring together appropriate senior people, most of whom have executive responsibility, from the cabinet and the ministries of agriculture, animal industry and natural resources; from economic planning and from education; from the public and private research institutions working in the country; and from the university faculties of agricultural and natural resources, of natural and biological science and of social science. Though the council as a whole would be consultative and advisory, its members severally must be able, each in his own sphere, to ensure effective and coordinated action. After review, the coordinated policy should issue from the cabinet office with the authority of government, and the members of the advisory and consultative body should be able to help, in the "constituencies," to carry it out.

A well-designed ASC would be a combined official-unofficial council whose members, but not the council itself, would have executive duties; it would recognize that ministries of agriculture, animal industry and natural resources are not the only government agencies concerned with policy for agricultural science; it would make a distinction between the formation of agricultural science policy (of which research policy is a part) and the formation and execution of programs of research (see below); and it would allow the universities to exercise their traditional and valued academic freedom in accordance with national purposes.

To provide for coordination with other national bodies concerned with science and its use in technology, some of the members of ASC should also be members of the National Council for Science and Technology (NCST) if one exists. In some circumstances it might even be appropriate for ASC to be a constituent or subordinated body of NCST. Other members of ASC should be members of the national universities council or equivalent body.

FORMING AND EXECUTING AGRICULTURAL RESEARCH PROGRAMS

In forming a national science policy for agriculture, the ASC will depend, to a large extent, on the suggestions and comments of agricultural research workers in many sorts of institutions; the science policy will define and include the research policy that the nation's research workers will execute.

To enable the agricultural research community to advise the ASC, and to coordinate their own work, an executive national council for agricultural research and scientific services (ARC) is essential. It will form research programs in accordance with the appropriate parts of the ASC policy. Some of the members of this body, which might or might not be a committee of ASC, should be drawn from ASC. It will have funds to enable it to carry out its program, whether in institutions of its own or in other institutions (including university departments), which it can aid with grants. It is essential to draw the holders of external research funds (such as international research institutes) into the council's work, even though they are not in any way subordinate to it; and indeed, in agreeing to externally funded activities of any sort, it would be right for government to suggest appropriate conditions to achieve this. Though the ARC might be serviced by the Ministry of Agriculture, it will usually be thought desirable for it to be financially separate, in respect to a substantial part of its funds; though other parts might be contributed by the ministry to support those parts of the ASC program in which the ministry was particularly interested.

This system separates the research and scientific services for agriculture from the administrative, fiscal and regulatory tasks–imposed by act of parliament or by decree–of the Ministry of Agriculture. Nonetheless, the Ministry of Agriculture (understood to embrace other ministries, if there are any, concerned with animal industries, animal health, fisheries and perhaps even forestry and wildlife) must have competent professional staff who are in touch with the practical problems of the farmers and the agro-based industries. They must also be professionally respected by the senior research workers in ARC institutes, universities and elsewhere, as well as by their own ministers and permanent secretaries. These people will be associated with the economic and technical investigatory and advisory services of the Ministry of Agriculture; indeed, it may often be wise to place specialist scientific services (e.g., in soil testing, plant and animal health) with that ministry–rather than with the ARC, as suggested above–in order to ensure a sufficient scientific presence there.

Reciprocally, the ARC and its senior scientists must be esteemed by their professional counterparts in the Ministry of Agriculture, and they must therefore be interested in and sensitive to the real problems of the industries. One of the most effective ways of doing this is to finance part of the ARC's program from ministry funds. Another is to include one or more agricultural economists on the ARC, and to ensure that each major agricultural research institute has an economic and–where appropriate–a rural sociology section, serving neither as an appendage nor as a fount of higher, but detached, criticism but as a participating part of the whole.

For those nations with few scientists, no university, and a small and hard-pressed civil service striving to cover all the governmental functions of a modern state, conventional wisdom calls for international cooperation between governments and regional institutions, and looks forward to broader economic and political associations of states. Against these concepts stand national sovereignty, international associations, different languages and differing national political and economic purposes, which are very real and cannot be wished away. The Economic Commission for Africa (ECA) and the institutions associated with the Organization of African Unity (OAU) seem likely, in the longer term, to be able to help the nations of Africa develop a collective science policy. In West Africa, the national governments, ECA, the International Institute of Tropical Agriculture (IITA), and the centralized French agricultural science organizations together have already been able to do much in a short time. The Consultative Group on International Agricultural Research of the United Nations (CGIAR), associated with FAO, will no doubt be able to extend its influence along these lines. The science policy group of UNESCO, which has already helped many developing nations in this field, has valuable contributions to offer.

Agricultural science serves agricultural policy. This is the major sector of economic development policy in most African nations, and development, in the last analysis, is the central business of national governments.

Since it will surely take some time before effective international institutional forms acceptable to independent governments can be devised and developed to enable the many African nations to form and implement science policies for agriculture, four transitional approaches are suggested:

1. Present modes of organization should be improved so that individual nations might take full advantage of the diverse scientific capabilities available to serve agricultural development. External assistance agencies might give valuable help here.

2. ECA, perhaps in cooperation with UNESCO, FAO, and the United Nations Development Program (UNDP), might facilitate practical cooperation in agricultural science policy by developing its international permanent professional machinery continuously to survey national programs, advise governments, and help to identify opportunities for economies and cooperation. As this machinery becomes more and more effective it will become increasingly useful to IITA and other international institutes associated with CGIAR and the foundations. The training functions, including workshops and seminars, of these international institutes will be particularly important, since they will help to develop professional associations and to ensure mutual understanding among individual workers. The "foreign" yet unofficial character of these institutes helps to make their service politically neutral and should therefore be assiduously preserved.

3. Bilateral foreign donors may also find it convenient to consider the advice of the ECA/UNESCO/UNDP/FAO machinery, if they find themselves in doubt concerning requests for support from individual nations in the field of agricultural science policy.

4. The Association for the Advancement of Agricultural Sciences in Africa (AAASA), as it evolves, should be able to develop very significant means of informal, unofficial, professional cooperation across language, geographical, and political boundaries. As AAASA members become accustomed to thinking collectively, and on a continental scale, about professional questions (including economic and social questions), they will surely be able, each in his own sphere, to ensure cooperation and more effective use of scarce scientific resources.

These four approaches, like the solutions to many other international problems in African development, depend intimately on language. Anglophone and francophone scientists are becoming accustomed to understanding each others' languages. Employers of scientists should be encouraged to plan the work of their staff so that they regularly attend a language laboratory during working hours to learn conversational English, French and other appropriate languages; in addition, salary scales should include inducements for reading and speaking fluency. Beyond this lies a clear need for language teaching texts and tapes in the natural and human applied sciences related to agriculture. A comprehensive English/French glossary of African agricultural terms, including vernacular names, would be extremely useful.

The African nations have been testing many different models, searching for an appropriate organizational structure for developing and implementing an agricultural science policy that will meet their special needs. The Nigerian government has recently created an organizational structure that approximates the one just described. The Ghanaian government has designed an institutional structure that has undergone considerable evolution, at one time simulating a pattern–Russian in style, but more recently reorganized along lines that are, in essence, Australian. In the Ghanaian situation, separation of teaching and research functions was at one time extremely sharp. The Ghana Academy of Sciences had responsibility for agricultural research, and the universities in Ghana mainly had responsibility for instruction in agriculture. This situation still exists, though to a lesser extent, between the Council for Industrial Research and the universities. The government of Kenya has not yet developed an agricultural science council, but Uganda recently formed one, and the government of Ethiopia has also created a science policy council. In Zaire, science policy formation rests with the Office National de la Recherche et du Développement established in 1967.

Quite soon after independence, most of the francophone African states agreed to coordinate research activities. They set up councils or committees of scientific and technical research that are official bodies, founded by governmental decisions, decrees or laws. Today, the secretaryship of the councils or committees is placed with the Ministry of Agriculture, research structures, or the presidency of the government or with the planning commissioner. The assignments of the councils deal mostly with agricultural research because, in many countries, that was the only scientific activity being carried on at the time of their formation. In most nations the councils or committees convene once a year. Heads of the departments for agriculture, animal production, rural engineering, forestry, and water resources participate in the meetings. So do the directors of the research centers, which sometimes include representatives of ministries (finance, planning) and of production or trade associations. The councils usually issue recommendations as to the orientation of research activities. Although they sometimes have permanent commissions or bureaus, they function as consultative bodies only.

Most of the councils were set up before the 1965 Lagos meeting that UNESCO convened on scientific policy problems in inter-tropical African states. Following a UNESCO meeting on scientific policy and research management (Yaounde, Cameroon, July 1967), some countries modified the arrangement of some of their scientific structures. Senegal, for example, first set up a Bureau for Scientific Affairs assigned to the President of the Republic. In 1971 this bureau was reassigned to the Secretary for Planning. It is charged with the responsibility of keeping a permanent inventory of studies being carried on in the various national or nonnational research centers in the country and of those being planned. A Department for Information Processing (a UNDP project) strengthens the bureau in obtaining scientific perspective. In the Ivory Coast, a State Ministry for Research was created in 1971. In addition, an Executive Council for Research and a Consultative Committee are to be set up. This ministry, with a very wide scope covering all the scientific activities of the country, will take over the long-existing but rather informal agricultural research committees, which met before under the supervision of the Minister for Agriculture.

CONCLUSIONS

Science policy for agriculture is crucial. In its absence, decision-making may become an unrelated, noncomprehensive, and perhaps even contradictory series of individual secondary decisions. To formulate science policy, some sort of logical, comprehensive, and all-embracing body, such as an agricultural science council, should be created.

Science policy is an important corollary of nation-building in Africa. African nations are undertaking a wide range of experiments in organizing their policymaking bodies so as to develop realistic goals and to manage wisely their natural, particularly agricultural, resources.

Formulation of policy requires an understanding of the full range of disciplines of the agricultural sciences and a knowledge of what these disciplines can do in the application of research on commodity improvement, and in providing an understanding of existing farming systems and the ways and means of creating new social systems that will operate in the best interests of the people.

In the execution of policy, the government must be informed and so advised that it can give appropriate attention to storing, retrieving and disseminating information on agricultural matters, to enlarging this body of information through research, to educating and training scientists, technicians and administrators, and to developing strong research centers that will integrate well with the institutions responsible for training and extension activities.

XVII

Communications

The Committee pointed out in the previous chapter that storing, retrieving and disseminating information, building libraries and publishing journals—communications, in short—constitute a vital aspect of science policy for agriculture. The media for this purpose have undergone phenomenal development in Africa. Even so, the growth is uneven and falls short of meeting the needs.

To analyze communications, we must ask: Who are the people it is important to inform? What information do "they" need? And where do the lines of communication need strengthening?

In the context of African agriculture, as in other areas, research workers must know what their colleagues are doing; donor agencies need to learn about needs and opportunities for technical cooperation and investment; governments must be kept abreast of research opportunities and results in order to establish policy; the extension worker needs something valid to extend to the farmer, and the farmer must be ready and able to accept some advice.

Building national research programs and establishing communication links among them from country to country are desirable. Breaking down the formidable barriers that rise between nations on the basis of agricultural research that they sponsor presumably in their own interest for national development is equally important; feasible alternatives for such barriers must be sought. But the real gap in communications lies in the chain of people and institutions through which research information must move to reach the farmer and, conversely, the selection of the key problems of the farm. This communication process can be represented by the "SMCR" model. For communication, a sender (S) sends a message (M) through a channel (C) to a receiver (R). There is an encoding of M by S and decoding of M by R. This latter process describes the language problem—the researcher must be able to speak the language (encode) that extension workers and farmers can understand (decode) and vice versa. The crucial point is that the channel of communication between researcher and farmer must be two-way, i.e., both must act both as sender and receiver. To do this successfully, each must be able to understand and appreciate the other's cultural outlook and capabilities. Currently, there exists an interruption in the channel. This gap could be closed by utilizing site-specific, adaptive research combined with demonstration programs to a much greater extent than they are used today (Figure 16).

CAPABILITIES

Research workers use a variety of means to keep abreast of the work of their colleagues. The individual scientist frequently seems to be able to

FIGURE 16 "Research information must move to reach the farmer. . . ." Veterinarians and Masai tribesmen, Kabete, Kenya. (Photo courtesy of Marc and Evelyne Bernheim.)

find the funds for meetings, travel, special studies and "retooling" educational experiences. Considering the rapidity with which advances take place in agriculture today, no scientist can work alone; if he does, he will find himself making poor use of his time and his facilities, duplicating unknowingly the work of others and unaware of discoveries that may parallel the goals of his own research. The local institutions that employ research workers must increasingly afford opportunities for their staff to participate in meetings, to visit their colleagues and to brush up their own academic and practical knowledge.

Commodity newsletters help to keep investigators working on the same crop in touch with their colleagues and informed about new developments. Cereal crop breeders circulate one such letter; so do those working on the roots and tubers. A newsletter is badly needed in grain legume research.

Researchers at outlying stations rarely have access to adequate library resources though they can and do rely on abstracting journals such as those issued by the Commonwealth Agricultural Bureaux, London, England. The East African Community recognized this need and set up a library service managed by the East African Agriculture and Forestry Organization. EAAFRO headquarters at Muguga already had a strong central agricultural library, and, with initial financial backing from The Rockefeller Foundation, it established a copying service. It now mails copies of the table of contents of the most recent journal numbers to researchers at some 42 experiment stations in East Africa and to others in Ethiopia, Zambia, Rwanda and other nearby nations. These researchers can then select the articles that interest them and have copies sent to them. Similar services ought to be set up for Central and West Africa. The EAAFRO system itself could be enlarged and improved by a program that would allow scientists to telephone research assistants at the headquarters and ask them to do the reference work so necessary to research. A biometrics service might also be supplied for analysis of data from the field.

A large number of associations and scientific societies have sprung up in Africa over the past several years; these serve a number of purposes. The Association for the Advancement of Agriculture Sciences in Africa (AAASA), for example, functions not only as a forum for research workers themselves but also as a place where investigators, representatives of donor agencies and government officials can meet and discuss mutual problems. Like its companion discipline-oriented associations or societies, it publishes a journal in which investigators can present their research results. To carry out these and related functions, the association needs sustained financial backing.

Certain other associations also influence research capabilities in Africa even though they are not devoted primarily to research. The Association of Deans of Faculties of Agriculture, for example, influences the manpower situation in the area of research when it considers the needs for postgraduate education. The Association of Principals of Agricultural Schools is filling a need in research when it pays attention to the problem of training technicians for work in research laboratories.

Multidisciplinary conferences, either permanent or *ad hoc*, foster understanding among research workers, donor groups and governments. The Conference of Directors of Economic and Social Research Institutes in Africa (CODESRIA) embraces 14 major academically oriented institutions. In association with Tufts University, it operates as a clearinghouse for information about work undertaken in these institutes. IITA, the Ford Foundation and IRAT jointly organize and finance a series of conferences in West Africa on such topics as animal production and roots and tubers. The Food and Agriculture Organization of the United Nations has brought together large groups of technical, administrative and scientific personnel working within specific ecological zones to discuss common problems.

The meetings, conferences and reports of scientific societies and associations are essential to representatives of donor agencies who need to evaluate priorities and capabilities for research. To these, FAO has added the Computerized Agricultural Research Information System (CARIS) pilot project, which is underwritten for funds and personnel by the Belgian, French and United States governments and The Rockefeller Foundation. CARIS collects and disseminates through published directories information on research institutions and on ongoing research projects in agriculture, animal production, forestry and inland fisheries. Fourteen nations of West Africa were chosen for the pilot project for two reasons: They experience the gamut of problems of the developing countries so that methods tested for this area are expected to be applicable to larger, perhaps worldwide, projects; and the data will be in two languages and will thus enable FAO to test and build the system in French and English.

In a specialized field, the Canadian International Development Research Center, FAO, IITA, French IRAT, and the Tropical Products Institute of the United Kingdom recently created a Group for Assistance on the Storage of Grains in Africa (GASGA). The group's objective is to provide developing African countries with information on the storage of grains and other agricultural products in a dry state. GASGA developed from the Seminar on Storage of Grains, Particularly in the

Humid Tropics, held at Ibadan in 1971 under the aegis of the Ford Foundation, IITA and IRAT (Ford Foundation, 1971).

Research councils (Chapter XVI) are of paramount importance as communication media to ensure that the research conducted in a country meshes with the economic and social development objectives of governments, and that governments are aware of advances in research that are significant for development. To this role may be added the benefits that can result from internationally organized workshops. In 1971, the National Academy of Sciences (NAS) of the United States, the Council for Scientific and Industrial Research and the universities of Ghana convened a workshop in Accra (NAS, 1971b). It drew together more than 250 Ghanaian researchers, professors, technicians, administrators and extension workers with specialists from the United States of similar background to discuss priorities in research for economic development. Had that meeting achieved no other results than to bring these various professionals together for the first time to discuss ways and means for making research and teaching in the agricultural sciences more effective and relevant to Ghana's needs, it would have been an extremely successful one. In fact, however, the workshop led to a subsequent workshop with the objective of helping the government of Ghana improve its extension service and decide on a science policy, with special reference to agricultural research.

Similarly, NAS organized a workshop in Zaire in mid-1971 with members of the National Office for Research and Development (ONRD). From this workshop emerged joint recommendations on demography, nutrition and economic development. There followed an international team of agricultural economists to advise the Zaire Ministry of Agriculture on the contribution of agriculture to Zaire's comprehensive plan for economic development.

The researcher has as much responsibility as policymakers or field service workers to communicate with the farmer and, in so doing, to understand the situation in which the herdsman or farmer operates and be aware of his needs and problems whatever the chain of command in the communication network. Otherwise, the problems that the investigator tackles may lack relevance to the situation and needs in the field. Here the lines of communication are especially tenuous and need strengthening.

Given research results that will truly benefit the farmer and the nation when applied, the administrative techniques become highly important. One of the most successful administrative systems in Africa has been developed at Ahmadu Bello University, Nigeria. In the six northern states the university has responsibility for both research and education in agriculture and for the support of extension workers in the state services. The Institute of Agricultural Research (IAR), for example, is guided by a Board of Governors, which includes representatives of the field services of the northern states of Nigeria that the university serves. The school of agriculture for this region, which gives intermediate level practical training and offers a diploma, is structurally a part of Ahmadu Bello University as is IAR. The faculty of agriculture within the university cooperates with the IAR field services units, and the school of agriculture. An extension–research liaison service of IAR ensures two-way information flow between research and extension staff. The University of Ife in the western state and the University of Nigeria at Nsukka, which serves the eastern states, benefit from ties to their respective states similar to those of Ahmadu Bello University in the North.

In contrast the University of Ibadan, which has traditionally been regarded as a federal rather than a state supported institution, has no administrative linkage with state field services units. It is beginning to develop linkage with the farm community through extension efforts that reside in the Department of Agricultural Economics. That department makes direct contact with several villages in the environs of Ibadan where the villagers have only a tenuous and casual contact with other sources of help. Professors and their students deal with the farmer, analyze his needs and help with advice.

Often the whole process of innovation may be disjointed. The farmer may lack information, even certain materials to apply new methods. Seeds may be available but no fertilizers; or, if they are available, they may be too expensive to apply, or, if cheap enough, the pesticides that are also necessary may be wanting. Farmer education, adult educational courses, short courses and field days—each can be extremely helpful in its own right; but comprehensive attention to the problem of improved agriculture is needed.

Clearly research workers need to learn more than they currently know about existing systems of farming, whether small-scale or plantation type, in Africa. Data on the success or failure of existing systems is lacking. In order to understand the reasons why existing farming systems remain as they are and, in many cases, resist recommended changes based on research results from experiment stations, the research worker (particularly the economist) must go directly to the villages. There he can collect data on all aspects of the farming process, from crop production to marketing, and thus understand why the farmer or herdsman makes the choices he does. Collecting data in this way, the research worker can make an extremely important contribution toward improving communications, while gathering the data that will give the reasons why, in so many cases, the innovations that may look good to the experimenter are simply not accepted by the farmer.

CONCLUSIONS

To promote agricultural research that will advance national development, researcher, teacher, professor, government administrator, policymaker, extension worker and farmer must communicate easily and effectively with each other; the gap in direct communication between farmer and researcher is too wide.

No single administrative system is going to accomplish the objective of bringing about effective utilization of research results at the farm level. However, a thorough understanding of existing farming systems gained through direct farmer/researcher contact of an analytical nature and involving deliberately planned and structured inquiry will go a long way toward identifying the obstacles that hinder acceptance of new techniques.

- *The Committee recommends that governments, donor agencies, academic institutions, and researchers themselves improve lines of communication, especially those that will enable the researcher to understand better which of the farmer's problems are most pressing and enable the farmer to appreciate the innovations the researcher has developed that are to his advantage.* This means increased farmer–researcher direct contact and improved field (extension service) operations.

XVIII

Institutions for Agriculture Research

During the past 50 years in Africa, as elsewhere, the institutionalization of agricultural research has been evolving in response to a growing complexity of problems and the need for interdisciplinary approaches to solve these problems. In this process, parallel trends have emerged, a national one looking inward toward the needs of the individual countries and an international one extending outward into the region beyond each nation.

NATIONAL RESEARCH INSTITUTIONS

Superficially, Africa would appear to be well-endowed with physical facilities for research. Collectively, the African nations support some 400 agricultural experiment stations covering all of the ecological zones and handling problems of all the commodities (Figure 17). Actually, organization and institutionalization of research has not kept pace with the needs of a growing population and with political change. Individual experiment stations need modernization; national networks of stations require streamlining.

To modernize their experiment station systems, the nations of Africa will need to rationalize the placement of existing field stations to agree with ecological zones and with the distribution of crop and livestock

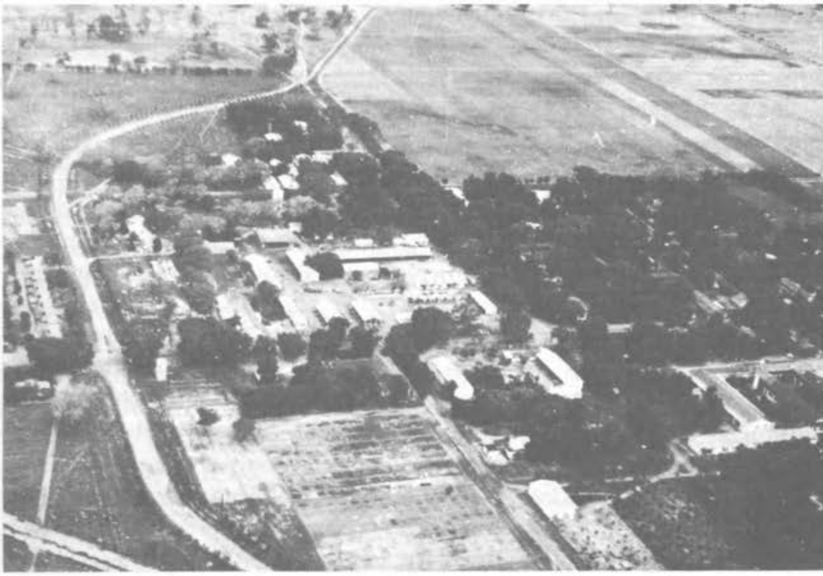

FIGURE 17 Centre National de Recherches Agronomiques, Bambey, Senegal.

production within national boundaries. They will need to forge links with university faculties of agriculture to engage student and professorial interest in solving problems relevant to national development; to continue to reorganize and adapt the wide ranging research institutes (built for other purposes during colonial days) to current and future agricultural needs in the modern political setting; to improve the quality of their staff; to relax cumbersome rules and constraining civil service regulations to permit flexibility and ease of operations; and to improve physical facilities of laboratories and staff housing that often do not command the priorities for state or donor agency funding.

One after another, African governments have sought aid to make their agricultural research stations effective. The Ethiopian government invited the United Nations Development Program to develop an agricultural research program in 1966. That program led to the creation of an Institute of Agricultural Research as an autonomous public authority of that government. The institute so created received support from a West German project that enabled it to establish one experiment station at Bako, while the UNDP group was building three research stations—one in the highland area where subsistence crops are grown, another in the coffee region, and a third in the Awash Valley where livestock is important. Although conceived of at first as commodity stations, these research facilities have since evolved into regional stations serving ecological zones.

The Kenya government organized an *ad hoc* research council in 1969 to assist the Ministry of Agriculture in planning research. This council dealt with research priorities in the interest of national development, experiment station organization, and terms of service of research workers. In 1971, the United States Agency for International Development responded to a request from the government of Tanzania to assess its agricultural research needs. The committee submitted its report (Sprague *et al.*, 1971) in April of 1972. Its recommendations, if followed, will help that government strengthen its existing network of research experiment stations. The government of Uganda invited an agricultural survey team sponsored by USAID and staffed by Ohio State University to evaluate that country's research program in agriculture and animal husbandry (Ferguson *et al.*, 1971). This team established four priorities: (1) coordination of research among the existing experiment stations and with the university, (2) coordination of research and extension, (3) training of personnel in agriculture, and (4) inauguration of a research unit in agricultural economics.

The government of Zaire is changing its emphasis from plantation crop to food crop research. Belgians in one program and American scientists in another under the aegis of the International Institute of Tropical Agriculture (IITA) and the International Maize and Wheat Improvement Center (CIMMYT) are assisting the government in maize and other cereal grain research.

Certain national research efforts have achieved international prominence because of the quality, scope and direction of the research undertaken: wheat research at Njoro, Kenya, maize research at Kitale, Kenya, and sorghum research at Serere, Uganda, constitute cases in point. For many years projects for the improvement of these crops have elicited support from donor agencies; research on grain legumes in the faculty of agriculture at Makerere University has drawn similar support.

In many cases, however, donor agencies have been reluctant to support national research programs that stand alone administratively but that may, nevertheless, have international potential through the quality and relevance of the research. They have opted to support those research programs that fit in an international administrative network involving two or more countries. Donor agencies should give greater emphasis to those national research programs that by quality and scope promise to have broad regional and international impact, whether or not intercountry administrative linkages already occur.

INTERNATIONAL AGRICULTURAL RESEARCH INSTITUTIONS

Research aimed at national development does not necessarily fan out beyond the boundaries of the nation; yet much agricultural research can best be handled on a broad geographical basis. Building the capabilities for conducting such research requires careful planning and understanding of national research priorities and capabilities. It is appropriate to consider founding an international institution, however, only when (1) the problems or needs for the research are common to several nations at least, and appear in those nations in much the same form; (2) the research on elements of the problems do not duplicate ongoing efforts in national programs or in other supranational institutions; (3) the problems are of priority sufficient to warrant a large scale effort; and (4) positive results may predictably emerge from the research sooner than they would if the same research were undertaken by existing institutions. Ideally, national agricultural institutions should exist that can make use of the results of research conducted at the international centers and vice versa.

Changing political conditions in Africa and the resultant changes in agricultural research constituencies naturally influence the effective life span of international research efforts. When the Agricultural Research Council was organized to serve the former Central African Federation (Northern Rhodesia, Southern Rhodesia and Nyasaland), that council recognized the impending birth of Rhodesia, Zambia and Malawi. Rather than build a strong central headquarters in one of those countries, the council wisely assigned field teams to the most appropriate station for particular areas of research in the three countries. When independence came, each of the nations had a stronger national experiment stations program than it might have had otherwise.

Today the agricultural and veterinary organizations, East African Agriculture and Forestry Research Organization (EAAFRO) and East African Veterinary Research Organization (EAVRO), that conduct research in Kenya, Uganda and Tanzania bend to the vagaries of the East African Community itself, to growing strength in national research efforts and to administrative impediments lingering from earlier times. Circumstances like these make it hard to recruit, develop and hold high-caliber staff. One solution to these problems might be for the community to isolate certain areas of research in a discreet internal institute operating with its own budget and upon its own administrative principles. Such an organization was mooted several years ago for the cereal crop and grain legume portions of agricultural research, which EAAFRO conducts.

The success of the international institutes up to the present seems to have rested on the problem-solving orientation of their programs on a few selected commodities—the basic food crops, for example. This approach lends itself well to campaigns for crop or livestock improvement. In 1968 IITA (Figure 18) was established in Africa to advance research on the basic food crops of the humid tropics. From its inception, IITA has been sharpening its priorities along this line, but at the same time including among its goals broad studies of the best ways of managing the environmental resources of the humid tropics in farming systems. International institutes can ensure continuity of effort by having staff of outstanding quality, effective outreach programs backstopped by work at the base station, and training programs that can meet flexibly the needs for skilled manpower of the governments they serve.

These basic principles notwithstanding, innovative, unorthodox organization and procedures may be advisable to ensure that the framework of future international institutions in Africa fit the problems in need of solution.

In Africa certain institutions may take on a coordinating role pri-

FIGURE 18 International Institute of Tropical Agriculture, Ibadan, Nigeria (F. F. Hill Administration Building).

marily. The West African Rice Development Association (WARDA), sponsored by UNDP and other donor agencies coordinates rice research and development of 14 West African nations (see Chapter IV). It assists them collectively on the assumption that each can function more effectively in conjunction with WARDA than it would by operating alone. The proposed comprehensive livestock center, which the Consultative Group in International Agricultural Research (CGIAR) is promoting (see "Conclusions and Recommendations," Chapter XIII), may build its program by supporting existing centers in Africa as well as by developing a strong research staff at a headquarters. Research on husbandry, management and breeding of livestock, according to some specialists, requires a widespread program of research.

In contrast, CGIAR is establishing a sharply defined international laboratory for research on animal diseases (ILRAD) in Kenya. ILRAD will consist of a central laboratory that houses a basic immunological program against the cattle diseases, East Coast fever and trypanosomiasis. The program will be conducted by a team of specialists in contributing disciplines using the costly and sophisticated equipment essential for advanced studies in this field. Existing research on these two diseases at other centers in Africa would form part of a broad cooperative program necessary to arrive at the ultimate objective—vaccines for the control of these diseases—but the cooperative nature of the research would be secondary to the program at the main laboratory and to training African immunologists there.

The international institutes can profitably develop liaisons with the faculties of agriculture of the universities and thereby help facilitate an even flow of ideas between fundamental and applied points of view. The International Centre of Insect Physiology and Ecology (ICIPE) created in 1970 helps orient university research toward practical problems usually considered the concern of government. ICIPE, though autonomous, benefits from its placement on the grounds of the University of Nairobi. Its director holds a university appointment. Conceived as a discipline-oriented institute, ICIPE's program has been evolving along ever more practical lines. Today it embraces studies on those insect species or groups of insects that appear to have profound economic importance to tropical African agriculture and human welfare—mosquitos (especially *Aedes aegypti*), tsetse flies, ticks (especially soft ticks), armyworms, and termites. The organization of ICIPE has certain unique features. The international board of directors that governs ICIPE is responsible for project research. The institute has an international consultative body drawn from the academies of sciences from many different European and African countries and from the

United States. It ensures the international excellence of the research and raises money from donor agencies. ICIPE has an African board of consultants, which ensures that the research program is directed toward problems affecting African agriculture in insect physiology, ecology and control. An important element of the association between the universities and ICIPE is the latter's objective in high-level training of young African scientists. Its emphasis is on postdoctoral training, a field hardly touched in Africa. But it does have programs also in postgraduate and technical training in specific insect science areas.

The Office de la Recherche Scientifique et Technique Outre-Mer (Figure 19), heavily supported by the French government, engages mainly in basic agricultural research, which provides the data and the solution to problems that other specialized agronomic institutes can take and apply. Its network of 20 research centers covers the various ecological zones and practically all of the francophone countries, and its research at central stations in the Ivory Coast, the Malagasy Republic and Cameroon underpins much of the applied research in food crop production in these nations of Africa. While it has little connection with university research in Africa, it accepts students and professorial staff on special assignment for training and research purposes.

FIGURE 19 ORSTOM Centre d'Adiopodoumé, Ivory Coast (Roubaud Laboratory and Plant Physiology Greenhouse).

As international institutes develop programs, their research horizons must constantly widen. The British-sponsored Cotton Research Corporation (See "Research Capabilities," Chapter X), which supplies cotton scientists for the official research services of many African countries, has found that research on cotton cannot stand or succeed alone. It has therefore, in cooperation with governments, added meteorology and crop rotations to its program. Even so, it has not yet fully grasped the consequences for its work of competition between cotton and other crops, and–between farming and other activities of the rural society–of competition for land, time, money and other resources. Similar enlargements and amplifications of programs have taken place on tea at the Kericho experiment station in Kenya, financed and supported by the tea growers and the tea processing industry of Kenya. The research staff there has conducted some extremely significant general research relating to mulching practices and root development as these relate to utilization of minerals in the soil. Even IITA, with an especially broad mandate for research on the basic food crops of the humid tropics, may have to extend its program north to the Sudanian zone, where three of the food crops common in the humid tropics–maize, rice and cowpeas–thrive. If IITA does amplify its geographical and crop emphasis, foci of cooperative research will have to be worked out with national experiment stations and international institutes such as the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT).

African international agencies are expressing increasing interest in agricultural and livestock research, especially at the applied level. Thus the Scientific, Technical and Research Commission of the Organization of African Unity (OAU/STRC) has taken responsibility for two major programs, one that is primarily of a research nature, cereal crop improvement, and the other mainly a campaign applying the results of research, the control of rinderpest. Both of these programs are seriously deficient in administrative and other types of support that should come from the international directing agency, and it is essential that OAU review its efforts in this regard and devise ways of giving efficient, effective leadership to these programs.

Building international institutes like IITA is becoming increasingly expensive, and it is not clear how many additional institutes of IITA scope can be built, notwithstanding the need for such institutes to deal with the agricultural and livestock research problems of the continent. Problems that relate to expense, program development, the possibilities of duplication of effort, and the like led to the creation of CGIAR, which now embodies nearly 30 governmental and other donor agencies and which—under the leadership of the International Bank for Reconstruction and Development (IBRD) [World Bank], UNDP, and certain governmental agencies—is taking the main responsibility for arranging the financing of existing international institutes and organizing new ones. Collectively, the international institutes CIMMYT, CIAT, IRRI, IITA, ICRISAT, CIP, ILCA and ILRAD have recurrent budgetary needs that alone have risen to nearly $35 million annually. Sums of this order of magnitude are beyond the possibilities of individual donars to supply; hence, the need for an international consortium of organizations to ensure that agricultural research in Africa, the Far East, the Near East, Latin America and Asia proceeds satisfactorily. While the total sum essential for recurrent expenditures for agricultural research on the basic food crops and livestock improvement looms large, it is, in fact, miniscule in terms of cost/benefit ratios. As the agricultural economist, Dr. T. W. Schultz, has shown (Schultz, 1968, revised 1969), insofar as one can estimate cost/benefit ratios, those pertaining to the research on maize and wheat alone in one institute—that which started out as the Mexican Agricultural Program and evolved into CIMMYT—have been in the neighborhood of 700–800 percent per year (cumulative). The financial problems of new models of international institutions, which are presently outside the ambit of CGIAR, such as ICIPE, present a special problem on a long-term basis. While they have still to prove themselves, they offer a new instrument for the solution of Africa's agricultural problems and should be given special consideration.

CONCLUSIONS AND RECOMMENDATIONS

Improving institutional research capabilities in Africa today will require a dual effort, monumental in terms of cost, directed toward national experiment station development in the first instance and toward international institute development in the second. The returns on investment to support these efforts will dwarf the cost.

- *The Committee recommends that priority be given to the centers for research on crop and livestock production in the Guinean and Sudanian zones.*

National research on maize, grain legumes, sorghum and the millets should be encouraged to interdigitate with the research under way at ICRISAT in India, for example, and with other national and international centers in Africa for research on these crops. Improving the quality of staff at research stations is of paramount importance. To accomplish this, governments will need to lift constraining civil service regulations, supply better laboratory and housing facilities, and develop better communications with university faculties of agriculture and with field service units.

National research stations must be encouraged to raise the quality of their research to meet international standards and to recognize the potential impact of that research on crop and livestock production beyond local boundaries, whether or not the administration and funding of research in one country interlaces with that of another.

• *The Committee recommends that donor agencies support national experiment stations more than they have in the past, especially in those projects that may have international impact through the quality and regional relevance of their research.*

Only through the success of national research programs can the developing nations acquire the mature professional scientific cadres without which their political independence must be incomplete.

To provide for the type of agricultural research that can best be handled on broad geographical bases and to support and supplement national efforts at the request of governments, international agricultural research institutions are essential.

• *The Committee recommends that the research on cereal crops and grain legumes in East Africa, currently the responsibility of EAAFRO, be greatly strengthened if not restructured within the community research organization.*

• *The Committee also recommends the creation of a germ plasm bank, particularly for cereals, but for other economic crops as well, for northeast Africa—the home of sorghum, millet and other economic plants.*

The research needs in Africa on the beverages is fairly well met through existing national research stations. IITA will soon fill the gap in the need for research on basic food crops of the humid tropics.

Pests and diseases receive attention on an international scale through a variety of international organizations; the most notable new institute in this area is ICIPE.

• On pests and diseases, *the Committee recommends that CGIAR and other international groups consider ICIPE deserving of amplified support.*

• On the matter of quarantines relating to the movement of genetic stock subject to pest attack and to diseases, an international effort of one kind or another will be needed.

• On livestock improvement, *the Committee recommends that CGIAR and the African governments move with all reasonable speed in developing the comprehensive animal improvement center; it also endorses and recommends support for the international immunological laboratory ILRAD to be established in Kenya, to provide the bases in fundamental strategic research and in training for immunological (vaccine), therapeutic or prophylactic treatment of trypanosomiasis and East Coast fever, the two outstanding diseases limiting livestock production in Africa.*

XIX

Manpower

This chapter in dealing with manpower, education and training for research focuses on human capabilities in the strictest sense of the word–distinct from those institutional and technical capabilities arising from availability of technical, physical and political resources. Research capability may, in this sense, be defined as the ability to use one's mental power to identify a problem accurately, to design experiments that will solve it in the quickest, most effective way, and then to execute those experiments. Academic institutions and governments have a responsibility to identify men and women who possess or can acquire this type of research capability, and to educate and train such men and women in appropriate numbers so that they may make the fullest use of these capabilities for the welfare of their nations.

Agricultural educational systems and research capabilities as defined above have existed in Africa as long as agriculture has been practiced, but concern today is in the area of confrontation between the traditional systems of Africa and those that are currently reaching Africa from abroad.

Traditional systems of educating and training men and women in Africa for undertaking research vary in concept and in implementation from place to place. Superimposed upon Africa's traditional systems are several others–most notably today the French and English systems.

These systems, each adjusted to meet conditions in Africa, offer contrast in several important aspects, but they share many more characteristics in common than is generally thought to be the case.

Almost without exception, the countries of Africa south of the Sahara offer undergraduate education in one form or another as well as intermediate level training. In anglophone Africa, nearly every one of the countries now has a faculty of agriculture offering undergraduate instruction to the B.Sc. degree. In francophone Africa, university level education is given in virtually every country, with the main universities located in Senegal, Ivory Coast, Cameroon, the Malagasy Republic, Burundi and Zaire. Francophone African countries have no postgraduate schools as such, but postgraduate studies are provided on a cooperative basis with French research organizations. Teaching of agronomy equivalent to the B.Sc. degree level does take place within special schools of agriculture, but the curriculum remains separate from the coursework that is given in other faculties of the university. In anglophone Africa, postgraduate centers are growing within several of the faculties of agriculture. These faculties also form part of the university framework, and traditionally they have presented material to the students distinct from the curricula offered in other faculties of the university and not interchangeable with it. In both French- and English-speaking Africa, many universities have now begun to blend the curricula of the faculties within the university, and to make both their teaching and their research relevant to the needs of governments and their institutions and, in these ways, to contribute more effectively to national development.

The objectives in preparing manpower for effective utilization of their capabilities in agricultural research may be met in a variety of ways, and the organizational patterns for doing so—while important—may matter less than educating men and women under one system who can understand those of another. For example, the need is great in both francophone and anglophone Africa for a bilingual capability among agricultural research workers to enable them to study under the different African systems. In conjunction with this, the various African educational systems must cooperate to move toward universal accreditation for the agricultural curricula and equivalency of degrees or diplomas.

The number of researchers and technicians needed in agriculture has been assessed frequently over the years. Most manpower surveys, if not all, have grossly underestimated the needs of agricultural research for manpower, though they have helped as general guides to the serious manpower gaps. The steady "brain drain" of qualified African scientists to other nations—and, within Africa, to administrative posts from research—leaves research posts mainly in the hands of a large expatriate population. As the latter depart, the need becomes even more acute for well-trained and well-educated African leaders in research.

In point of numbers, technicians with intermediate training or agronomists with the equivalent of a bachelor's degree are in extremely short supply, even though intermediate level instruction is offered in virtually every African country. For peak output, each research worker may need from 5–10 technicians. But the researcher in agricultural sciences with a master's or Ph.D. degree is also in extremely short supply. The Committee's priorities point first to an increased output of leaders at the apex of the educational pyramid (postgraduate studies), who can plan and execute the research programs in agriculture that meet the needs of national development; of second priority is the training of greater numbers of those whose abilities and interests lead them into field service or laboratory technician careers.

GRADUATE INSTRUCTION

To expect that each nation will develop its own capabilities for offering postgraduate studies in the agricultural sciences within the foreseeable future would be unrealistic. Moreover, the flow of ideas and techniques at the postgraduate level should be encouraged through the interchange of students from one African university to another and through African student interchanges with universities abroad. It is becoming possible to achieve this interchange and at the same time reduce the brain drain by modifying scholarship awards so that students may do their thesis research in Africa, yet satisfy residence and course requirements abroad. Good local supervision is required for programs of this sort to be effective. The Committee strongly supports this type of arrangement and endorses also home country institutional or government sponsorship that requires graduate students to return to their place of employment in their home country upon the completion of their foreign experience.

For the present, the need for graduate instruction in Africa can be met at several centers. In West Africa, the University of Ibadan, Nigeria, has instituted postgraduate studies in agriculture for students who come from other countries of West Africa as well as from Nigeria. The faculty of agriculture of the University of Ibadan (Figure 20) is beginning to require its postgraduate students to take courses to complement and supplement their research. Makerere University of Uganda offers postgraduate instruction in a number of disciplines; emphasis on staff and student participation in research projects that relate to the needs of Uganda is an innovation in this faculty.

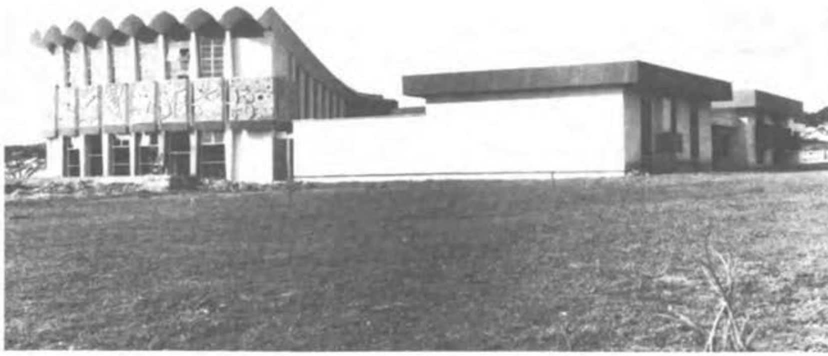

FIGURE 20 Dean's Office building and and lecture hall, Faculty of Agriculture, University of Ibadan, Nigeria.

The faculty of agriculture established at the University of Nairobi in Kenya in July, 1970, began that very year with postgraduate research. The faculty is especially strong in research in agricultural entomology, plant breeding and agricultural extension methods. The research work in the faculty is closely correlated with that of national and regional research institutions. It would seem essential to identify the growth points of relevant agricultural research in Africa and to give regional assignments for building up research capabilities in these areas to faculties of agriculture with the relevant existing capabilities. In this way, a loose network of regional centers could be established with a mission to develop their special areas of relevant postgraduate capabilities.

At these and other institutions, stability and career responsibilities need to be built into the deanship posts if cohesiveness and continuity of instruction and research at the postgraduate school level is to be achieved. In francophone Africa, some postgraduate instruction is actually given by the Office de la Recherche Scientifique et Technique Outre-Mer (ORSTOM) centers and by those institutes constituting the Groupement d'Études et de Recherches pour le Dévelopement de l'Agronomiques Tropicale (GERDAT), usually in connection with universities in France. For satisfactory geographical coverage and to meet the demands for well-trained and well-educated agricultural scientists, a postgraduate center ought to be established in cooperation with the existing research institutions in francophone West Africa and Central Africa.

UNDERGRADUATE INSTRUCTION

Undergraduate education and training in agriculture must satisfy a group of objectives wider than those of preparing men and women for research and teaching posts. In this regard, many students view undergraduate instruction and the B.Sc. degree merely as stepping stones to graduate instruction and to teaching and research posts. Others, who will terminate their studies with a B.Sc. degree, may visualize the experience as one preparing them for positions in the administrative and field services units of the ministries of agriculture and other government agencies or as a gateway to agribusiness. Whatever their aspirations, many students are not finding the jobs in the agricultural profession for which their undergraduate work should have prepared them and go, therefore, into totally unrelated fields of employment.

This situation led to the 1971 statement of the Vice Chancellor (Dr. H. A. Oluwasanmi) of the University of Ife:

> It is sad to report that in spite of the enormous amounts of money we vote every year for agriculture, and in spite of a hundred years' existence of scientific agriculture in this country, the technology of agricultural production in Nigeria remains essentially a hoe and cutlass affair. Highly trained agricultural scientists cannot find openings in agriculture. Out of the 85 Agriculture graduates that this University turned out between 1966 and 1970, 25 could find nothing else but schoolroom jobs in this country. It cannot be said that a situation in which Agriculture graduates are misemployed is a true indication of our desire for rapid agricultural development.
>
> Because the hoe and cutlass remain the tools of cultivation, our youths naturally look down on agriculture as a means of livelihood. They move into the cities in search of white-collar jobs. In order to correct this situation it is essential for our Agriculture graduates to remain in agriculture. To ensure that this happens, our Governments must re-examine their priorities for agricultural development in a bold and imaginative manner [Oluwasanmi, 1971, pp. 11-12].

But, as Dr. Oluwasanmi stresses, it is not so much lack of B.Sc. degree holders that is the problem, as it is the lack of synchrony between agricultural training and education at that level and government policy for agricultural development.

Policymakers in African nations might consider designating agriculture as a distinct profession requiring registration, as occurs in medicine and—to some extent in some countries—veterinary science. Qualification for the profession would then require that university preparation be thoroughly reviewed. In addition, formulation of these qualifications would require a clearer idea of what an agricultural scientist is expected to do. The consequences of these considerations might well be to elevate the agricultural profession in the minds of Africans so that youth would be challenged to enter this field of acknowledged scientific and technological endeavors.

The stature and usefulness of undergraduate education as a pathway to an agricultural career in its own right is weakened by the lack of clarity about what a student with a B.Sc. degree is qualified to do. This is especially true in government positions where holders of the degree are in competition with those who come from specialized nonuniversity schools that offer two to three years of technical training leading to a diploma. In establishing policy, governments should set standards that will give appropriate awards to the holder of a B.Sc. degree, and universities should make undergraduate education in agriculture really applicable to the needs of government and industry. These steps should help limit the wastage of B.Sc. holders who should enter the field service (extension) and technician (laboratory) occupations so important to the execution of research and dissemination of research results.

The entrance qualifications required of incoming university students should also take into account careers that may be open to them when they complete their studies. For example, the National University of Zaire undertook a review of its educational system in terms of Zaire's needs. As a result, the university may revise the entrance requirements and its curricula. The newly proposed curriculum for agriculture would introduce an initial 2-year period of practical training as part of the undergraduate instruction. This would prepare students who do not wish to pursue an academic course for certain posts in government service. These two years would be followed by basic fundamental science courses for those who did continue and would give them grounding in the academic subjects important for subsequent graduate studies or for a wider variety of job opportunities at the B.Sc. level. The new curriculum, which is organized along functional rather than along traditional lines of the discipline, should prepare students for certain broad categories of careers likely to be opened to them in various agricultural branches of government. In fundamental reorganizations of this sort, government and academic institutions would need to recognize the danger of too rigid a preparation for existing careers that might disappear.

Haile Selassie I University in Ethiopia recently carried out an internal review of its education system to bring instruction in that university in juxtaposition with the needs of the people in Ethiopia. This review expressed a need common to many African countries—producing textbooks written in the vernacular by scientists who are nationals and who can inpart to students the experience they have gained living and working under local conditions.

INTERMEDIATE LEVEL TRAINING

How to identify individuals who have the right qualities to manage an experiment station successfully and to train people to do so constitutes another important need. Intermediate level training as it is currently offered in the specialized institutes in anglophone Africa prepared the bulk of the manpower for the official agricultural services—field supervisors, technicians and specialists to care for and feed livestock and other animals. This level of training needs to be re-examined and altered to ensure that the training tailored for specific jobs in government important for national development does not limit the upward mobility of the student with that training in academic, as well as practical, fields. Moreover, if the curriculum for the undergraduate in agriculture embraces greater emphasis on technical training to complement the academic instruction, as it is likely to do, then duplication in objective to earn a diploma from an intermediate level institution or a B.Sc. degree from a university faculty of agriculture will have to undergo review.

Where manpower shortages are acute, the faculties of agriculture should encourage students to handle some of the routine technical aspects of research that, under other circumstances, might be done by technicians. In fact, governments are already applying pressure on the universities and institutes that offer intermediate level training to ensure that instruction and/or academic experience financed through taxes relate to the important problems of national development. If the universities and other institutions do not respond to this need, alternative educational institutions may in fact spring up to satisfy it.

EXTRACURRICULAR AND ON-JOB TRAINING

Whatever academic level or degree of skill the student attains in a recognized intermediate-level training school, an essential relationship in the training process is his association, in a work experience, directly with researchers at experiment stations (Figure 21). Work experience as in-service training is a characteristic of the education system in francophone Africa; ORSTOM, in particular, offers in-service experience to trainees at different levels and under different conditions. It may give them a thorough specialization in a field of service that may take two or three years to complete, or it may offer refresher courses to specialists of different levels and for experiences of varying lengths of

FIGURE 21 Agricultural students in the metalworking shop of the teaching and research farm, University of Ibadan, Nigeria.

time. Other of the specialized institutes forming the agricultural research network of francophone Africa give similar types of training experience.

In anglophone Africa, the International Institute of Tropical Agriculture (IITA) is related closely with the University of Ibadan and its faculty of agriculture. Not only do some of the staff members of the institute hold adjunct appointments at that faculty, but students enrolled as undergraduates may carry out their research on the IITA station grounds under the supervision of the IITA staff. IITA-university relationships have been expanded to include cooperative arrangements in graduate student training with other African universities and with universities in Europe and North America. In an integrated relationship between the field services, the research staff, the school, and the faculty of agriculture of Ahmadu Bello University in Nigeria, students are encouraged to work with research institute staff members. In similar fashion in Uganda, government and university staff are making efforts to bring the government station activities at Kawanda and those of the faculty of agriculture at Kampala and Kabanyola close together. As pointed out in Chapter XVII, the newly created association of deans of agricultural faculties can and should become a powerful force to bring about adjustments of the kinds just described, to ensure that agricultural scientists are appropriately educated and trained in order that they may make their maximum contribution to the development of their countries.

CONCLUSIONS AND RECOMMENDATIONS

The Committee concludes that the most important priority for improving African agricultural research capabilities is to build a strong cadre of well-educated and well-trained men and women in agricultural sciences and to ensure that those who are trained and educated receive an educational experience that focuses on the application of their capabilities toward national development. This priority transcends those outlined for specific research advances on commodities and on the farming systems. In pursuing this aim, *the Committee recommends*

- *that the existing regional centers for postgraduate studies be greatly strengthened and supported, by donor agencies as well as by government.* Curriculum development in them should emphasize course work to accompany research, emphasize agricultural problems of practical importance to the African nations over problems of an academic or fundamental nature, and furnish continuity in administrative strength and position at the leadership level.
- *that undergraduate instruction at the B.Sc. degree level be recast, to have greater worth in its own right in preparing graduates for careers at the completion of their studies at that level*, and to give the students a cohesive professional attitude toward their careers. In this respect programs on agriculture as a professional career should be re-examined and new curricula established for this purpose; furthermore, it should be possible to register agriculture as a profession.
- *that the usefulness of training and education for the field services and laboratory assignments in Africa be studied comparing that gained from the undergraduate curriculum in the university with that gained from specialized institutions of intermediate level training outside the university structure.* The objective should be to bring about more effective ways of assuring upward mobility of students from technical to research and other more advanced professional activities, but also to see that intermediate level training is clearly focused on the main band of career opportunities that will be open to B.Sc. degree candidates upon completion of their studies.
- *that in-service training at the international research institutes and at the national agricultural experiment stations be greatly amplified at all levels.*

XX

Conclusions and Recommendations

This study outlines areas in which the NAS Committee on African Agricultural Research Capabilities believes more knowledge is needed to support agricultural development, and it suggests means by which this knowledge may best be gained and used. The study takes place against the background of a continent whose central band has recently transformed from colonial to independent government and given birth to 38 nations. It presumes that, for the foreseeable future, Africa will rely most heavily on the agricultural sector for lifting the standard of living of its peoples in the face of population growth rates ranging from 2.3 to 2.6 percent per annum and of increases in the absolute numbers of people living on farms.

In determining priorities in agricultural development, national decision makers need the help of research to predict the consequences of alternative courses of action whether at enterprise, whole farm, community, sector, national or regional level.

- *The Committee recommends that all efforts be made to bring natural and social scientists to work closely together in conducting research that will help national decision makers predict the consequences of alternative courses of action in determining priorities in agricultural development.*

The Committee points to three broad problem areas as key ones urgently in need of solution in Africa:

1. improving standards of nutrition and raising the level of food production to satisfy rapidly increasing market demands (i.e., to improve standards of living while providing a constant, more rapid flow of raw materials for national industries, substitutes for agricultural imports and crops for export);
2. helping to alleviate the uneven development that takes place between farm and nonfarm sectors of the rapidly growing economies of African nations; and
3. ensuring that agricultural research contributes properly to a sound national agricultural policy and that agricultural policy itself plays its appropriate role in national and international science policy.

- *Toward these ends, the Committee recommends that, in technical and related socioeconomic areas, the priorities for strengthening research capabilities be in the areas of farming systems, food crops and livestock improvement in that order.*

Agricultural development reinforced by strong agricultural research requires an adaptable infrastructure for policy. Regulatory practices dealing with quarantines and with pesticides will need changing as new pests and diseases cross borders and as information on host-parasite relationships develops. Advisory councils for government; communication networks that interlace scientist, government official and farmer; agricultural experiment stations; and faculties of agriculture–all need constantly to adjust to the kaleidoscopic changes that agricultural development in Africa, or elsewhere, brings.

Specific recommendations in respect to quarantines and pesticide usage occur under separate headings in this chapter. Communications so vital to functional relationships between farmer and researcher are discussed under the section on farming systems. Specific recommendations on research institution building and on improvements of faculties of agriculture are also treated in separate sections below. Here, the Committee wishes to stress the importance of forming appropriate scientific councils or other advisory bodies to put agricultural research results to work. Many of the countries of Africa have been drawing upon English, Australian, Russian, French and other models for the development of scientific councils in building their own systems; they have consulted with national academies of science, multilateral international agencies, and with academic and governmental bodies.

• *The Committee recommends that ongoing mutually productive cooperative efforts of forming appropriate scientific councils or other advisory bodies to put agricultural research results to work be intensified,* not only for the immediate benefits that will accrue to the nations of Africa but also for the potential advantages that result from a general expansion of knowledge in the area of advisory relationships between science and government.

FARMING SYSTEMS

A thorough knowledge of the existing farming systems of Africa, including those of livestock, farming and crop production, is a prerequisite for any kind of research activity in agriculture in Africa that is expected to be put to use. At present no such thorough knowledge exists; although in several isolated instances research into farming systems has, of course, taken place. Research on farming systems is fairly strong at Ahmadu Bello University in northern Nigeria, at Bambey in Senegal, and at ORSTOM in Ivory Coast, and this subject is one of the main program thrusts of the international institute IITA. Research at these centers cannot suffice for that which ought to be undertaken on farming systems in other countries of Africa in other agricultural centers.

• Therefore, *the Committee recommends that governments and donor agencies place priority on projects aimed at gaining a thorough knowledge of farming systems, especially those that will yield primary data from working farms.*

Primary data is lacking on farming systems; it must be collected from working farms. Such data will facilitate research on soil and water management, research on optimum crop sequences, and introduction of new or improved crops or cropping practices, which must be acceptable to the farmer before they can be integrated within existing farming patterns or be substituted for traditional systems.

Related to the need for primary data is the crucial need for interchange of information in general between scientists and farmers; i.e., for innovations to be worthwhile, there must be a climate of cooperation wherein the researcher can learn from the farmer which of his problems are important for the researcher to attempt to solve and which of the innovations that the researcher can offer are to the farmer's advantage to accept (see Chapter XVII). Normally, the acquisition and distribution of such knowledge falls to extension or field service units. No single administrative system, however, is likely to bring about effective utilization of research results at the farm level. Direct farmer/researcher contact involving deliberately planned instructive inquiry of an analytical nature will go a long way toward the identification of the obstacles that hinder acceptance of new techniques.

- *The Committee recommends that the extension and field service institutions be strengthened and rendered far more effective than they are at present, and that the farmer/researcher avenue of communication be widened above all others.*

Selective research needs to be undertaken on ways in which the farm families' labor resources can be more fully utilized and some of the drudgery taken out of hoe-and-cutlass farming through selection or development of implements (handtools and motor- and animal-drawn equipment) that would overcome seasonal labor bottlenecks and improve the timeliness of farm operations, thus increasing the return to labor employed on the farm.

- *The Committee recommends that the use of power, whether through the employment of machinery or human labor, receive intensive investigation.*

In most African countries, markets for modern factors of production (seeds, planting materials, fertilizers, pesticides, herbicides, specialized equipment, vaccines, etc.) are controlled in whole or in part by government. The same is true of the markets for many of the export and industrial crops, as well as for some food crops in some individual countries. Further, these markets are often managed to promote industrial and urban development and export earnings.

- *The Committee recommends that the economics of production, of management, and of marketing be investigated as they affect farming systems in the context of changing social and cultural patterns in urban and rural Africa.*

COMMODITIES

Food Crops

The panoramic view presented by this study of agricultural research under way in Africa to raise food crop production and the capabilities extant for conducting such research, may create an illusion that every crop and every research discipline has adequate coverage; in truth, however, critical gaps exist in each field of endeavor, in each crop, and within the geographical range of that crop. For example, in many countries, lacunae exist in research coverage of groundnuts, a potentially important food crop; the indigenous vegetables, which comprise a substantial part of the diet of both the rural and urban African populations, have been almost entirely neglected in many countries. Research on fruits, strong in the francophone countries, is not as strong in the anglophone ones. In the dry land areas bordering the Sahara, the need for research may be one primarily of improving agronomic practices because varieties of maize well-adapted to that area are already at hand that may yield 3-times that of the local varieties; in the humid tropics of West Africa, however, the need may be to create varieties that do well and have good quality in warm humid conditions.

In general, the Committee would assign first priority for intensifying research programs to the cereals–maize, rice, sorghum, the millets and wheat (see "Recommendations," Chapter IV). Collectively, the cereals cover a wide geographical range in Africa, feed the majority of the people, offer great potentiality for providing animal foodstuffs, and may well contribute substantially to off-farm sales in the world market. The grain legumes–cowpeas, groundnuts and soybeans–receive second priority for their potential role in improving African nutrition; the roots and tubers–cassava, yams, sweet potatoes–receive third priority for their vital role as a source of food in the humid tropics where cereals (rice excepted) do poorly. The Committee cautions that any strict adherence to the above outlined priorities would be to oversimplify the situation.

- *The Committee recommends that administrators, researchers, farmers and others analyze each geographical region thoroughly in order to settle upon the specific crop and the specific problem where research can be most productive.*

Ideally, agricultural research to bolster development should follow an orderly sequence–first, refinement of those agronomic practices that push local varieties beyond their present capacity to respond in yield and quality; second, improvement of varieties for quality and yield; third, invention of methods to control the pests and diseases, which are attracted to new varieties; and fourth, where local surpluses begin to appear, implementation of post-harvest protection for the produce and processing for its utilization–all within the context of evolving socioeconomic situations that may impede or encourage agricultural development in a given locality.

Germ plasm improvement, the problem area where most has already been achieved, should continue to command priority and sustained support. Africa possesses a wealth of germ plasm of an indigenous nature still to be tapped. As yet, no sustained research effort has taken place in Africa to improve the millets, but—as has been demonstrated experimentally—millets can serve as parents for interspecific crosses with elephant grass to produce better forages. Stocks of high-quality maize are needed. Wheat research will need to keep ahead of the most important diseases that attack wheat, the rusts. The potential for upgrading grain legumes, particularly cowpeas, is enormous. Varieties of soybeans adapted to the African climate have still to be produced. The range and productivity of the Irish potato could be extended into warmer climates. Research on tomato, onion, etc. has only begun to become important in some of the highland areas of tropical Africa and in the drier parts of the lowland tropics.

Practically, the bottlenecks to agricultural production identified on the spot will govern the priority accorded to improving agronomic practices, improving varieties, controlling pests and diseases and developing post-harvest technology.

- *The Committee recommends that any specific technological problem on food crop production be researched within the framework of agricultural technology applied to that crop in accordance with the concept of the "package of practices" as developed worldwide through Green Revolution experience on wheat and rice.*

Animals

For the African people to benefit fully from the wealth of animal resources of their continent, research on domesticated stock, wildlife, and fisheries will have to be amplified; all species need attention, but research on some will give greater overall returns than research on others.

- *The Committee recommends that research priority be assigned to domesticated stock, especially the ruminants, and that, among the ruminants, first attention be accorded to cattle for the production of meat.*

Research on animal production including nutrition, management and breeding has been spotty and insufficient, due in part to the high cost that research on large animals entails. New and improved research approaches are urgently needed to increase forage production and to provide protection or controls to prevent overgrazing. Breeding livestock for adaptability to the many different environments of Africa and for resistance to disease presents problems that are international in scope, requiring clarified objectives.

- *The Committee recommends that African governments, together with interested international organizations, support programs continental in scope that will answer such questions as how much effort should be applied to upgrading stock, how much to the introduction of new stock, and what is possible to achieve and reasonable to recommend in cattle improvement and production practices, if one considers the socioeconomic patterns of life of Africa's rural people.*

A few specialized cattle diseases have commanded attention in years past, especially trypanosomiasis and East Coast fever. Both are killer diseases of cattle; trypanosomiasis, in addition, produces sleeping sickness in man. Strong research support is still urgently needed, not only to achieve the practical objective of producing vaccines for control of these diseases, but also for the scientific breakthrough that may be imminent in developing vaccination or immunizing techniques effective against the protozoan organisms that cause them.

- *The Committee strongly recommends building, on a multi-institutional basis (which will include ILRAD), the physical plant and manpower capabilities in immunology in Africa essential for developing effective vaccines that will control the blood-borne parasites that cause East Coast fever and trypanosomiasis.*

QUARANTINE

The movement of plant and animal material for breeding, for other research purposes and for trade has steadily increased over the past 25 years. This increase came as a result of the availability of and the demands for new and improved plant and animal stock from many parts of the world. For a variety of reasons, quarantine regulations have often not reflected the latest information on range and distribution of pests and diseases. Among other constraints, overburdened physical facilities have caused damaging delays in the movement of disease- and pest-free stocks from one country to another and into the continent from abroad. Quarantine procedures need to be set and implemented, and sometimes removed precisely and quickly, to permit the easy flow of disease- and pest-free genetic stock to satisfy these demands.

National governments, of course, have the ultimate responsibility for deciding upon the quarantine regulations appropriate to their host–pest (or host–parasite) situations, for building adequate facilities to handle the plant and animal quarantine testing load, and for ensuring that well-trained personnel man these services. Governments must periodically review the quarantine protocols to ensure that these protocols not only maintain the vital objective of keeping out the diseases and pests not in the area under quarantine, but also that they remain realistic in terms of the constantly changing host–parasite relationships and that outdated regulations are eliminated.

Regional and international organizations can be helpful by encouraging the development of regional, as well as national, quarantine stations in Africa and by helping to draw up quarantine protocols generally acceptable to African governments.

- *The Committee recommends that an international team of specialists, knowledgeable as to government interests and the state of agricultural research, be formed to analyze quarantine problems in Africa thoroughly, as a first step in the establishment and implementation of improved quarantine measures appropriate to Africa as a whole and to each nation in particular.*

PESTICIDES

The application of modern technology to farm practices will inevitably push the African farmer to increase his use of pesticides. Whatever the negative factors that might limit the general application of pesticides—their hazardous nature, and the effects they might have on environmental quality—pesticides will be in agricultural use for years to come. Legislation and enforcement of regulatory practices on the sale and use of these pesticides are sadly lacking in Africa.

- *The Committee recommends that governments enact legislation to regulate all facets of the use of pesticides, and that efforts in the training and strategic employment of plant and animal protectionists be accelerated.*

INSTITUTIONS

The agricultural research institutions (experiment stations, for example) that house staff and embrace research programs must be resilient and responsive to changing research needs; these needs afford great scope for continuously improving the structures, organization and management of such stations. Employing and keeping high-caliber staff at national research stations is of the first order of importance.

• *The Committee recommends that governments furnish better laboratory and housing facilities, develop better communications with university faculties of agriculture and with field service units and ensure that government experiment stations offer salaries and conditions of service competitive with those of other institutions.*

National research stations must be encouraged to be international in the range, quality and impact of their research, whether or not one government's administration and funding of research interlaces with that of another.

• *The Committee recommends that donor agencies support national research program development more than they have in the past.*

National research on maize, sorghum, the millets and grain legumes should be encouraged to interdigitate with the research under way at international centers as well as at other national centers for research on these crops. For the agricultural research that can best be handled on broad geographical bases, international agricultural research institutions are essential whose programs are designed to meet the needs of more than one government.

• *The Committee recommends revamping the institutional organization of cereal crop and grain legume research in East Africa, currently the responsibility of EAAFRO.*

• *The Committee recommends, in addition, creating a germ plasm bank, particularly for cereals, but for other economic crops as well, for establishment in northeast Africa.*

The research needs in Africa on the beverages is fairly well met through existing national research stations.

• *The Committee recommends that the individual nations of Africa keep their institutional capabilities strong for research on the beverages and other commercial crops (coffee, tea and cocoa primarily, but also cotton and groundnuts) from local budgetary sources and/or from returns on the sale of these commodities.*

IITA will soon help fill the gap in the need for research in basic food crops of the humid tropics.

• *The Committee recommends that donor agencies continue to provide substantial support to the newly established international institutes—IITA, for example—and to those institutes whose programs are of a long-term nature that require sustained financing.*

Many pests and diseases are best investigated on a broad ecological and geographical basis. While substantial resources have already been devoted to basic biological studies on selected problems, such as coffee berry diseases and locust invasions, more initiatives need to be taken in the direction of controlling rodent and bird pests. A notable new international institute, ICIPE, is directing its entire research capacity to the problems of insect pests of crops and livestock.

• *The Committee recommends that ICIPE and similar initiatives be given support on a priority basis in filling the gaps in research in plant and animal protection.*

CGIAR and the African governments have been developing a comprehensive livestock improvement center (ILCA). This center is now established in Ethiopia, and the Canadian IRDC is serving as executing agency for the center. CGIAR has also been organizing the proposed International Laboratory for Research on Animal Diseases to be created in Kenya as a center for basic immunological investigations and for the training of Africans in this field. The Rockefeller Foundation has been designated executing agency for ILRAD.

• *The Committee believes the creation of the International Livestock Center for Africa (ILCA) and of ILRAD figure among the most important steps taken in international institutional development and that the proposed institutes will be filling important needs; accordingly, the Committee recommends that CGIAR continue to enlist support for the creation of these two institutions.*

• *The Committee recommends that donar agencies, African governments, agricultural institutes and the agricultural science community at large strengthen the recently established independent multidisciplinary Association for the Advancement of Agricultural Sciences in Africa, which provides the only comprehensive bilingual professional forum for* *the biological, physical, chemical and socioeconomic sciences related to agriculture throughout Africa.*

The small executive unit at Addis Ababa should be reinforced to help AAASA to identify and develop specific programs of international professional activity and to obtain funds from donors for the development of the program, which may well extend over a period of 15 years.

MANPOWER

Highest on the list of priorities for improving African agricultural research capabilities—transcending those priorities outlined for specific research advances on farming systems and on commodities (crops and livestock)—is to build a strong cadre of well-trained and well-educated men and women in the agricultural, physical, biological and social sciences whose educational experiences have been focused on the application of their capabilities in research toward national development.

Toward this end, *the Committee recommends that*

- *through support of donor agencies as well as of government, the existing centers for postgraduate studies (at the University of Ibadan and at Makerere University, for example) be greatly strengthened, their curricula emphasize course work to accompany research, and a larger proportion of their research be directed toward problems of national import;*
- *the universities of Africa devise better ways of ensuring continuity of leadership and policy, not only for department heads but for the deanship post as well, in order that faculties of agriculture and veterinary medicine may develop cohesive programs pointed toward national goals* (i.e., increase the tenure of the Dean and strengthen the line of authority from the Vice Chancellor to the Dean, etc.);
- *instruction at the B.Sc. degree level be recast so that the B.Sc. degree, and the education it represents, possess greater worth in preparing graduates for careers at the completion of studies at that level.*
- *training and education for the field services and laboratory assignments in Africa be reviewed, and the undergraduate curricula in the university compared and rationalized with the curricula in specialized institutions of intermediate-level training outside the university structure* (and more effective ways devised to assure upward mobility of students from technical to research activities); and
- *in-service training at the international research institutes and at the national agricultural experiment stations be greatly amplified at all levels.*

IMPLEMENTATION

Once specific advances are discovered and have been accepted, agricultural development takes place swiftly and needs for research change. Research priorities and capabilities must adjust with equal rapidity to the new situations created by such advances. Though the projections in this report are designed to span decades, agricultural change is likely to leave this report with a short half-life. Accordingly, the need will periodically arise to assess the African agricultural research situations and to revise this and subsequent studies to accommodate advancing national goals, which likewise will be changing kaleidoscopically. To meet these challenges, *the Committee recommends that*

- *this report be evaluated approximately 5 years after it is issued and periodically thereafter in the light of current needs, priorities and goals by groups in which African agricultural scientists and socioeconomists (possibly designated by AAASA) would have a progressively increasing leadership role alongside donor agencies and governments;*
- *since the recommendations call for action at government and regional levels, ECA be closely involved in the implementation process;* and
- *international, private and bilateral donor agencies be informed of the major conclusions of the present study and of future evaluations so that they may act together to support those national or regional programs that need external assistance.*

Glossary of Acronyms and Abbreviations

AAASA	Association for the Advancement of Agricultural Sciences in Africa
AAU	Association of African Universities
AFA	Association of Faculties of Agriculture
ARC	Agricultural Research Council
ARCN	Agricultural Research Council of Nigeria
ARI	Agricultural Research Institute (Ghana)
ARI	Animal Research Institute
ARS/USDA	Agricultural Research Service, U.S. Department of Agriculture
ASC	Agricultural Science Council
ASRI	Academy of Sciences Research Institute
CARIS	Computerized Agricultural Research Information System
CEEMAT	Centre d'Études et d'Expérimentation du Machinisme Agricole Tropicale
CEP	Centre d'Étude des Pêches (Chad)
CGIAR	Consultative Group on International Agricultural Research
CIAT	International Center of Tropical Agriculture [Centro Internacional de Agricultura Tropical] (Colombia)
CIDA	Canadian International Development Agency
CIEH	Comité Inter États des Études Hydrauliques (Senegal)
CIMMYT	International Maize Improvement Center [Centro Internacional de Mejoramiento de Maiz Y Trigo] (Mexico)
CIP	International Potato Center [Centro Internacional de Papa] (Peru)
CRC	The Cotton Research Corporation

CODESRIA	The Conference of Directors of Economic and Social Research Institutes in Africa
CRI	Crops Research Institute (Ghana)
CRIG	Cocoa Research Institute of Ghana
CRIN	Cocoa Research Institute of Nigeria
CRRP	Centre Régional de Recherche Piscicole
CSNRD	Consortium for the Study of Nigerian Rural Development
CSIR	Council for Scientific and Industrial Research
CSRS	Centre Suisse de Recherche Scientifique (Ivory Coast)
CTFT	Centre Technique Forestier Tropical (Ivory Coast)
EAAFRO	East African Agriculture and Forestry Research Organization
EATRO	East African Trypanosomiasis Research Organization
EAVRO	East African Veterinary Research Organization
ECA	Economic Commission for Africa of the United Nations
FAO	Food and Agriculture Organization of the United Nations
FDAR	Federal Department of Agricultural Research (Nigeria)
FDFR	Federal Department of Forestry Research (Nigeria)
FDVR	Federal Department of Veterinary Research (Nigeria)
FFPRI	Forest and Forest Product Research Institute
FFS	Federal Fisheries Services (Nigeria)
FGLGB	Federal Grain Legume Gene Bank (Nigeria)
FIIR	Federal Institute of Industrial Research
FMD	Foot-and-Mouth Disease
FPC	Firestone Plantation Cy
FPQS	Federal Plant Quarantine Station
FPRI	Forest Products Research Institute
FPRU	Food Preservation Research Unit
FRI	Food Research Institute (Ghana)
FRCRU	Federal Root Crops Research Unit
GASGA	Group for Assistance on the Storage of Grains in Africa
GERDAT	Groupement d'Études et de Recherches pour le Développement de l'Agronomiques Tropicale (France)
HSIU	Haile Selassie I University
IAEA/FAO	International Atomic Energy Agency
IAR	Institute for Agricultural Research, Ahmadu Bello University (Nigeria)
ICIPE	International Centre of Insect Physiology and Ecology (Kenya)
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics (India)
IBRD	International Bank for Reconstruction and Development [World Bank]
IDRC	International Development Research Center (Canada)
IEMVT	Institut d'Élevage et de Médecine Vétérinaire des Pays Tropicaux
IFAC	Institut Français de Recherches Fruitières Outre-Mer
IFAN	Institut Fondamental d'Afrique Noire
IFCC	Institut Français du Café, du Cacao et Autres Plantes Stimulantes

IITA	International Institute of Tropical Agriculture (Ibadan, Nigeria)
ILCA	International Livestock Center for Africa (Addis Ababa, Ethiopia)
ILRAD	International Laboratory for Research on Animal Diseases (Nairobi, Kenya)
INEAC	Institut National pour l'Étude Agronomique du Congo, now INERA
INERA	Institut National pour l'Étude et la Recherche Agronomique (Zaire)
INRA	Institut National des Recherches Agronomiques (Dahomey)
IRAD	Institut des Recherches Appliquées au Dahomey
IRAT	Institut de Recherches Agronomiques Tropicales et des Cultures Vivrières
IRCA	Institut de Recherches sur le Caoutchouc en Afrique
IRCAM	Institut de Recherches du Cameroun
IRCN	Industrial Research Council of Nigeria
IRCT	Institut de Recherches du Coton et des Textiles Exotiques
IRHO	Institut de Recherches pour les Huiles et Oléagineux (Congo)
IRRI	International Rice Research Institute (Philippines)
IRSAC	Institut pour la Recherche Scientifique en Afrique Centrale
IRSM	Institut des Recherches Scientifiques Malgaches
ISABU	Institut des Sciences Agronomiques du Burundi
ISAR	Institut des Sciences Agronomiques du Rwanda
ISM	Institut Scientifique du Mali
IWP/FAO	Indicative World Plan of the Food and Agriculture Organization
LPV	Laboratoire de Protection des Végétaux
MBG	Mission Biologique du Gabon
MDR	Agricultural Research Service of Ministry of Agriculture (Upper Volta)
MRCN	Medical Research Council of Nigeria
NAS	National Academy of Sciences of the United States
NCST	Nigerian Council for Science and Technology
NIFOR	Nigerian Institute for Oil Palm Research
NITR	Nigerian Institute of Trypanosomiasis Research
NSPRI	Nigerian Stored Products Research Institute
NSRCN	Natural Sciences Research Council of Nigeria
OAU	Organization of African Unity
OAU/STRC	Organization of African Unity/Scientific, Technical and Research Commission
OCAM	Organisation Commune Africaine et Malgache
OCCGE	Organisme de Coordination et de Coopération pour la lutte contre les Grandes Endémies
OCLALAV	Organisation Commune du Lutte Antiacridienne et de Lutte Antiaviaire (West Africa)
ODA	Overseas Development Administration (United Kingdom)
OPRC	Oil Palm Research Centre (Ghana)
ORANA	Organisme de Recherches pour l'Alimentation et la Nutrition Africaine
ONRD	National Office for Research and Development (Zaire)

ORSTOM	Office de la Recherche Scientifique et Technique Outre-Mer (France)
PAG	Protein Advisory Group of the United Nations
RRIN	Rubber Research Institute of Nigeria
ROKUPR	See WARDA
SAPH	Société Africaine de Plantation de l'Hévéa
SHP	Service Hydro-Pedologique
SODEPALM	Société pour le Développement et l'Exploitation du Palmier à l'Huile
SRI	Soil Research Institute (Ghana)
STRC	See OAU/STRC
TRB	Tobacco Research Board (Rhodesia and Nyasaland)
UNDP	United Nations Development Program
UNESCO	United Nations Education, Scientific and Cultural Organization
USAID	United States Agency for International Development
USDA	United States Department of Agriculture
WARDA	West African Rice Development Association
WHO	World Health Organization of the United Nations
WMO	World Meteorological Organization of the United Nations

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Resource Materials

Throughout this report, especially in those sections that deal with the present status of research and with research capabilities, the Committee has made suggestions as to sources of information about agricultural research in Africa. These suggestions, together with the literature actually cited, constitute but a fragment of the wealth of published material about African agricultural research, much of it emanating from Africa itself. The Committee makes no attempt to present a thorough review of the literature, but it does wish to point out general types or classes of publications to which one can go in order to explore in depth special facets of agricultural research and development in Africa.

The individual who wants more information according to specific disciplines of agricultural research should consult *Tropical Abstracts*, issued by the Royal Tropical Institute in Amsterdam. A phenomenal proportion of the abstracts in this abstracting journal, which is worldwide in its coverage, comes from African sources.

For statistical information about agricultural production and marketing, publications of FAO and of the USDA's Office of Information and its Economic Research Service and of USDA/USAID's Foreign Economic Development Service proved valuable to the Committee.

Much of the information in this report comes from unpublished internal documents, some of them restricted in distribution and limited in number of copies. This type of document provided a great deal of material for the Animal Resources chapter. Foundations, IBRD and other agencies prepared a whole series of documents in preparation for the creation of the two animal research organizations in Africa, ILRAD and ILCA. One would have to appeal directly to the agency involved to obtain such publications.

Nearly all of the agricultural research stations in Africa, whether they depend from ministries and departments of agriculture or from universities, issue annual reports. These may be delayed in publication, but they constitute extremely important sources of information. Some stations, EAAFRO of the East African Community and the Institute of Agricultural Research of Ahmadu Bello University in Nigeria, for example, publish newsletters which have articles of substance in them and bring one up to date with the latest advances in research achieved at the station.

The number of professional societies in Africa is growing. The Association of African Universities (AAU), AAASA, the Association of Faculties of Agriculture in Africa (AFAA), as well as national professional associations, are representative of these. Their publications, in addition to providing outlets for the articles of individual scientists, give information on their own policies and objectives as regards agricultural research and training.

Institutions outside of Africa specialize in certain fields of African agricultural research. Thus, at the University of Michigan, interest focuses on problems of employment, on simulation and sector studies, and to some extent on integrated rural development as these subjects affect African agricultural development. One can readily ascertain the interests of bilateral and multilateral donor agencies by consulting the special studies they have financed and implemented in preparation for possible investment and by reading the announcements of the awards that they make.

A number of ten year summary reports, those of ORSTOM and of IRAT for example, are extremely useful. Other special reports, including those from IBRD and others printed by commercial concerns, give good roundups of the status of production and of research. Certain books, for example those of the Longmans Tropical Agriculture Series, deal with special commodities; they extend to a wider field and go well beyond Africa.

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