Chapter 5

The Role of Technology in Enhancing Low-Resource Agriculture

CONTENTS

Boxes

Tables

Chapter 5

The Role of Technology in Enhancing Low-Resource Agriculture

HIGHLIGHTS

- Many agricultural and environmental problems facing Africa reflect a failure of traditional systems to accommodate the continent's rapidly increasing population. In most of Africa, the tradition of land-extensive, shifting agriculture will have to evolve into more intensive, permanent agriculture if food security is to increase. Technological innovation will play a major role in this intensification process.
- A technological approach with promise for promoting food security in Africa calls for an evolution of existing agricultural systems based more on sequential improvements in technology and incremental gains in productivity, as compared to the quantum increases in inputs and output that epitomize the so-called Green Revolution. Some high-potential areas in Africa will be able to follow the latter approach, but these areas are in a minority and Green Revolution technology will do little to address the needs of the majority of African agriculturalists who function under resource-poor conditions. A viable technological framework to assist low-resource farmers, herders and fishers should account for the following:
  - Successful development of Africa's highly diverse farming systems will require an equally diverse array of technologies adapted to local socioeconomic and environmental conditions. Although Africa will benefit from the fruits of global agricultural research, African problems will require increased emphasis on Africa-specific solutions.
  - Increased farmer participation in identifying problems and acceptable solutions could enhance the effectiveness of technical assistance. Existing farmer practices should be the starting point for integrating the best of traditional and modern technologies.
  - Technologies in support of low-resource agriculture should reflect the high premium this practice places on risk aversion and the need to maintain flexibility in the face of uncertainty and limited access to resources.
  - Resource-poor agriculturalists rely primarily on internal resources. Consequently, information for intensive management and other technologies should emphasize the use of internal resources also.
- Technologies that offer the most promise for contributing to the food security of resource-poor farmers and herders share common characteristics. These include technical and environmental soundness, social desirability, economic affordability, and sustainability.
- Promising technologies outlined in this report appear to be able to significantly improve Africa's future food security through improving the use of natural resources, increasing soil fertility and water availability, providing genetic improvements in crops and livestock, improving integrations of animals into cropping systems, and reducing food losses and workload. However, technologies do not operate in isolation and non-technical factors will heavily influence the extent to which this technical potential is realized.

TBCHNOLOGY'S PLACE IN A CHANGIN6 AFRICA

Technological innovation in low-resource agricultural systems will be a major factor contributing to Africa's ability to meet the challenges ahead. However, technical solutions alone will not solve Africa's food security problems.

Throughout the world, agricultural systems have met increasing food needs by intensification, and technology has always played an important role in this process. Through more active management and application of technology and other inputs, it becomes possible to expand and accelerate agricultural production beyond that possible by relying on natural processes alone. However, much crop and livestock production in Africa is extensive rather than intensive. A small percentage of African food production is likely to remain extensive where population densities are still low, or where people have settled in new lands opened by disease control, for example. In areas like these, shifting agriculture historically has been an ecologically sound and labor-efficient means of producing food. In fact, until recently, shifting agriculture was sustainable in much of Africa because fields could be cultivated for perhaps 5 years in semi-arid zones or 1 to 3 years in more humid areas, and then allowed to lie fallow for 10 to 15 years to restore the land (42,47,50). As populations increased and as land became more scarce, however, this age-old agricultural method began failing. As fallow periods shortened, yields have declined, additional marginal land has been put into production, and environmental degradation has accelerated (45).

Livestock production faces a similar situation, particularly on Africa's rangelands. Indigenous systems have developed to use scarce, often unreliable, natural resources efficiently. Recent studies show these systems to be much more efficient than previously believed (3,15). Yet it is evident that in more and more cases, traditional practices are no longer sustainable. One contributing factor is the increased numbers of pastoralists and livestock. Perhaps more detrimental, however, is the increasing conflict over land and resources as farmers extend further into rangelands and as pastoralists are forced onto rangeland of marginal productivity and lose access to critical dry-season forage (27).

Declining per capita food production and income, as well as serious degradation of the resource base on which African development depends, provide compelling evidence that resource-poor farmers, herders, and fishers will require additional technology and technical assistance to intensify their agriculture. The rate at which intensification will need to take place, or even the extent to which intensification is possible, obviously varies greatly in a region as diverse as Sub-Saharan Africa.

But what form should technical assistance take? A review of the disappointing results to date suggests that technological interventions often overemphasize solutions imposed from the outside. These commonly fail to consider local perceptions and social and environmental conditions, and tend to underemphasize more integrated approaches to problem-solving (51,52).

The prospect that Africa will need to double its agricultural production over the next few decades to keep pace with population growth is daunting. It also has given rise to the notion that nothing short of a Green Revolution approach for Africa, such as the one that transformed much of Asia's agriculture, will meet this challenge. Certainly a few areas of Africa, notably the regions with high agronomic potential and well-developed infrastructure, have benefited from technology developed in Asia, but it seems unwise to expect a Green Revolution strategy to be widely applicable to Africa in the foreseeable future (box 5-1). In comparison to those parts of Asia that benefited from the Green Revolution, Africa has poorer soils and less water available for agriculture; lower labor/land ratios; less developed human and institutional infrastructure; and it relies on not one but several staple crops, most of which have short research histories (4).

Box 5-1.—The Green Revolution and Africa

When people talk about African agriculture, they often compare the continent and its problems to India in the mid-1960s, when that country faced massive food problems, was heavily dependent on emergency food aid, and was often written off as a "basket case. " If India can make the progress it has—and today India is exporting food, including food aid to Africa—why can't Africa? The answer is simple, although the context is complex: Africa and India are two very different places and some of the most useful lessons from the Indian experience are drawn from highlighting those differences.

Climatic and Physical Differences

The dramatic gains in Indian agricultural output occurred largely in the Punjab, an area with relatively fertile soils, a geology that permitted the widespread adoption of irrigation, and few pest problems. The high-yielding varieties of the Green Revolution were bred to perform best under such conditions. In contrast, African soils are generally low in fertility. They tend to be shallower, have poorer texture, are more inert, and have lower water-holding capacities than comparable Indian soils (32). Also, African geography is less conducive to irrigation, especially large-scale projects. In Africa, only 3 to 5 percent of cultivated areas are irrigated whereas at least 20 percent of Indian's cropland is (11,55),

In Africa's high-rainfall areas, agricultural production is limited by low sunlight, rapid leaching of soil nutrients, soil degradation when crops are removed, and the rapid spread of pests and diseases. Production in semi-arid areas is limited by lack of rainfall. West Africa's semi-arid areas tend to have shorter growing seasons with greater risk of drought than the semi-arid areas in India with similar levels of rainfall. This suggests that shorter growing-cycle crop varieties are needed and these are generally more risky,

Crop Differences

Rice and wheat, the predominant Green Revolution staples in India, have a long history of scientific research. Also, the environmental conditions of the Punjab allowed India to introduce improved varieties and adapt them quickly to local conditions, The successes with rice and wheat were partly a function of plant breeders' ability to develop photo-period insensitive varieties that could be adopted over a wide geographic area. No such varieties seem to be on the horizon for millet, sorghum, or the other 10 main staple crops in Africa. For example, there has been little success in introducing improved Indian sorghum and millet varieties into West Africa because of disease and pest problems, and water control problems have prevented the introduction of dwarf rice varieties. Only 2 imported rice varieties of 2,000 tested performed as well as local varieties in 10 years of experiments. Modern crop breeding research has begun only recently for other African staples, such as roots and tubers.

Economic Differences

The spread of new varieties in India was fostered by a better transportation network and more highly integrated markets for inputs and crops than exist in Africa (21). Another important difference is that while India is a large, relatively closed economy, African economies are typically small and depend heavily on foreign trade. Indian political leaders could make the decision to concentrate agricultural research on one high-potential region (the Punjab). This type of decision is politically difficult if several countries are involved. Moreover, small countries may not have the critical mass of scientists to support agricultural research, but multi-country regional research is often difficult to coordinate. Open economies are more susceptible to fluctuations in international prices, especially for their main export prices. Government revenues, and hence, agricultural research budgets, depend on export earnings and are highly unstable as a result.

The relative prices of land and labor are also quite different between Africa and India. In India, land is scarce, while labor is abundant. Consequently, agricultural technologies were developed to be land-augmenting and labor-using. In Africa, seasonal labor bottlenecks and highly variable rainfall are major constraints, while labor is abundant at other times of the year. Hence, Africa's pressing agricultural needs include technologies to relax these constraints, such as selective mechanization and plant varieties that are bred for yield stability. As population pressures increase, however, the need for more land-augmenting, labor-using technologies will increase.

(continued *on* next page)

Differences in Human Resources

A key factor in India's success in agricultural research was the heavy prior investment that the country had made in human capital and in developing the research and training institutions that then generated both trained scientists and knowledge about the country's agriculture. India began building colleges of agriculture in the 1920s under the British colonial government, so by the 1960s Indian policymakers and scientists were very knowledgeable about the nature of the problems facing agriculture in that country, where the highest payoffs to research were likely to be, and which parts of the country had the greatest agricultural potential. This knowledge was then used to focus domestic and foreign assistance research efforts.

In contrast, African countries have until recently devoted little investment to training agricultural scientists or building research institutions. The lack of trained personnel and knowledge of local agricultural conditions in much of Africa severely limits the effectiveness of foreign assistance and places too much reliance on expatriates, Also, Africa has yet to develop an educated lobby for agricultural policymaking such as emerged in India in the 1960s.

Lessons for Africa

The Indian experience shows that progress in overcoming food problems in poor countries is possible, but that it is a long-term process that depends not so much on importing new technology from abroad, although that may be important, but on developing indigenous capacity in the agricultural sciences and in policy analysis. These skills allow a country to borrow judiciously from abroad and adapt foreign technologies to local conditions, as well as to develop new technologies locally. Developing this knowledge and scientific capacity in Africa is a long-term process; without such capabilities the effectiveness of foreign technical assistance is likely to remain low, But India's experience shows that technology itself is not enough. Supporting institutions are extremely important also.

SOURCE: John M. Staatz, "The Potential of Low-Resource Agriculture in African Development, " contractor report to the Office of Technology Assessment (Springfield, VA: National Technical Information Service, December 1987).

This is not to suggest that the situation in Africa is hopeless. Some technical progress is being made that justifies cautious optimism. However, rather than relying on the relatively homogeneous package of technologies and inputs that produced a dramatic Green Revolution in Asia, more viable approaches for promoting food security in Africa call for evolution of Africa's existing farming systems. An approach suited to enhancing African low-resource agriculture involves sequential improvements in technology that provide incremental gains in productivity, as well as greater stability of production. The technological framework entails a more diversified approach whereby technologies are better suited to the needs and characteristics of Africa's wide range of small-scale, resource-poor farming systems.

Much uncertainty surrounds the issue of the availability of technologies for this task. Some experts feel that domestic and international researchers "have not produced a large enough stock of technological innovation capable of ensuring sustainable growth in aggregate agricultural output" (43). Others believe that the necessary technologies exist, and the problem is their poor adoption rates. This uncertainty reflects, in part, an imbalance between the emphasis given to research at the experiment stations and the relative neglect of on-farm, adaptive research. The people working more closely with farmers and herders seem less optimistic regarding availability of suitable technology.

While OTA's analysis suggests that certain types of technical interventions can help improve food security significantly, it would be irresponsible for donors to place all their African agricultural development eggs in one basket. Successful approaches will be a thoughtful, integrated approach—a mix of objectives and programs reflecting the diversity that exists in Africa—but technical assistance certainly will need to address low-resource agriculture more than it has in the past. The following sections provide a general framework and present specific findings regarding technology's role in improving low-resource agriculture. The chapter concludes with a general discussion of the overall potential of technology to promote improved productivity and sustainability of low-resource agriculture.

WHAT IS A PROMISING TECHNOLOGY?

One of the most important lessons to arise from past development assistance failures is that to be successful, technical interventions must match the specific constraints shaped by local social and environmental conditions. How, then, can OTA speak of promising technologies for the whole continent of Africa? First, OTA classified Africa into four agroecological zones based on the U.S. Agency for International Development's refinement of the United Nations' Food and Agriculture Organization (FAO) work on Africa's soils, climates, and crops. Then OTA consulted development experts familiar with each of these zones to identify technologies that they believed held the most promise for increasing the availability and stability of 1ocally produced food. These consultations included a telephone survey, Advisory Panel meetings, two workshops, and production of a series of background papers on individual technologies (app. A, B).

Table 5-1 summarizes the specific promising technologies addressed in this report along with their geographic applicability and their primary benefits. Each of these technologies is appropriate for application in certain agroecosystems at particular times. An important criterion in choosing these technologies is their compatibility with the nature of low-resource agriculture and the guidelines for effective development assistance presented in chapter 4. A close match suggests a high probability that they will be accepted by low-resource farmers and herders and that they can be used effectively.

Technologies that offer the most promise for contributing to the food security of resource-poor farmers and herders share common characteristics, including:

- *Technical and environmental soundness:* This means they are able to stabilize, if not increase, production while ensuring conservation of natural resources.
- *Social desirability:* This means technologies must address farmer-identified problems and constraints. In addition, they should attempt to minimize the disruption of existing farming systems.
- *Economic affordability:* This means that resource-poor farmers, herders, and fishers must be able to obtain and maintain the

Table 5-1.— Promising Technologies and Practices by Agroecological Zone[a]

Technology and practices	Zone[b]	Primary benefits
Improved use of soil and water resources		
Soil *and water management*		
Recession farming	A,S,H	Labor-efficient method of growing crops using water from annual floods; expands area under cultivation
Water harvesting microcatchments	A,S	Increase water available from rainfall
Planting and building bunds on the contour	A,S,H,T	Increase water available from rainfall; reduce soil erosion
Tied ridges	A,S	Increase water available from rainfall
Drainage practices	H,T	Enable production on land that would otherwise be waterlogged
Terracing	T	Reduces water and soil runoff; enables cultivation on steep slopes
Minimum tillage, mulching and other soil-conserving vegetation practices	S,H,T	Prepare land without incurring costs of plowing (soil erosion, excessive leaching and compaction); organic residues and mulch help maintain fertility, reduce water and soil runoff

Table 5-1.—Promising Technologies and Practices by Agroecological Zone[a]—Continued

Technology and practices	Zone[b]	Primary benefits
Improving soil fertility		
Biological nitrogen fixation . . .	A,S,H,T	Increases nitrogen availability
Vesicular-arbuscular mycorrhizae.	A,S,H,T	Increase phosphorus availability
Manuring	S,H,T	Increases soil organic matter and soil fertility
Phosphate rock	A,S,H,T	Increases phosphorus availability
Commercial fertilizers	A,S,H,T	Increase soil fertility
Small-scale irrigation		
Gravity diversion: channeled systems	A,T	Increase water availability
Gravity diversion: poldered systems.	A,S,H	Increase water availability
Mechanically fed: water lifting.	A,S	Increases water availability
Mechanically fed: water pumping	A,S,H,T	Increases water availability
Improved cropping practices		
Intercropping	A,S,H,T	Reduces risk of crop failure; increases seasonal availability of food; reduces pest and disease problems; improves efficiency of resource use
Home gardens	A,S,H,T	Increase seasonal availability of food; improves nutrition in the diet
Agroforestry		
Dispersed field tree intercropping ... , ...	A,S	Increases soil organic matter; provides source of fodder, fuelwood, poles
Alley cropping	S,H,T	Increases soil organic matter; provides source of fodder, fuelwood, poles
Windbreaks	A,S,H,T	Decrease wind damage, especially to seedlings; decrease evapotranspiration; provide source of fodder, fuelwood, poles
Live fencing and other linear planting.	A,S,H,T	Provides source of fodder, fuelwood, poles, fencing
Genetic improvements		
Crop breeding.	A,S,H,T	Provides resistance to diseases and pests; tolerance to environmental stress; improves yield
Animal breeding	A,S,H,T	Provides resistance to diseases and pests; tolerance to environmental stress; improves yield
Improved use of animals		
Mixed crop/livestock systems using small ruminants	A,S,H,T	increase income; improve diet; reduce risk through diversification
Animal traction.	A,S,H,T	Reduces drudgery; improves labor productivity; extends area of cultivation
Aquiculture.	A,S,H, T	Provides source of protein; recycled nutrients; source of income
improved systems to reduce pest-loss		
Integrated pest management		
Quarantines.	A,S,H,T	Reduce risk of accidental introduction of pests
Host resistance	A,S,H,T	improves resistance to pests and disease
Cultural controls	A,S,H,T	Reduce pest populations by manipulating farming practices, especially by intercropping and rotating crops
Biological controls.	A,S,H,T	Reduce pest populations by using natural enemies
Pesticides	A,S,H,T	Reduce pest populations by using natural or synthetic biocides to kill pests, limit their fertility, or disrupt pest development
Post-harvest technologies	A,S,H,T	Improve processing and storage of foods; improve nutrition; reduce labor
Improving animal health		
Veterinary support	A,S,H,T	Reduces animal mortality and morbidity
Animal nutrition	A,S,H,T	Increases productivity; improves feed use efficiency; reduces susceptibility to disease

[a]See box 3-4 for a map of Africa's agroecological zones.
[b]Key to agroecological zones: A = Arid/Semi-Arid, S = Subhumid Tropical Uplands, H = Humid Lowlands, T = Tropical and Subtropical Highlands.

SOURCE: Office of Technology Assessment, 1988.

technologies. In Africa, this generally means a need to use resources internal to the farm rather than externally purchased inputs.

- *Sustainability:* This means that technologies are environmentally, socially, and economically feasible to maintain in the long term. Especially given Africa's rapidly increasing populations, this requires technologies that enable farmers to take additional steps toward modernization as they become feasible.

IMPROVING THE EFFECTIVENESS OF TECHNICAL ASSISTANCE TO RESOURCE-POOR FARMERS, HERDERS, AND FISHERS

Chapter 4 outlined four concepts important to enhancing low-resource agriculture. These concepts have implications for selecting, developing, and disseminating technology. Also, OTA derived findings from the detailed information on technologies in chapters 7 through 11 and the 16 contractor reports on technology on which those chapters are based (app. A.) These findings, then, represent common threads and conclusions gleaned from this various material.

Finding 1; **Technologies do not operate in isolation and they are affected by non-technical as well as technical factors. A systems approach to agricultural development would consider how national level decisions on issues such as fixed crop prices, land tenure, and incentives for conservation, affect farm level decisions, and it would consider potential interactions among social, economic, and environmental factors on the farm.**

A variety of national-level decisions affects low-resource agriculture. Technical assistance to low-resource agriculture will be more successful if national governments have the capacity and inclination to provide support for the process. Economic considerations such as ensuring adequate prices and affordable inputs for producers can act as important incentives in determining whether resource-poor farmers, herders, and fishers will find it in their interest to increase productivity by investing in new technology. In Zimbabwe, for example, the government set favorable grain prices and provided farmers with access to credit, extension, inputs, and markets. Small-holder farmers responded by tripling their maize production between 1980 and 1985, when it reached 1.6 million metric tons—so percent of Zimbabwe's total production (41).

Secure land tenure and conservation policies are two critical non-technical factors operating at the national level that affect the adoption of several technologies discussed in this report. For example, mulching and other soil-conserving practices often have an immediate expense to the herder or farmer: foregone fodder and/or land that could have been used for crop production. These methods have little chance of success unless a commitment exists at the national level to conserve soil and water resources, and some assurance to the individuals who bear the costs that they will share in the long-term benefits. As it happens in developed countries, developing country governments will need to provide incentives encouraging conservation measures so the entire burden is not borne by individual farmers and herders (26).

Social, cultural, and economic factors at the household level also determine the acceptability of a particular intervention. For example, developing crop varieties capable of dramatically increasing total yields serves little purpose if the varieties are not acceptable because of taste preferences, cooking quality, or storage requirements. The relative success of hybrid maize in Kenya and Zimbabwe, compared to the low adoption rate in Malawi, illustrates this need for a holistic view. Farmers in Kenya and Zimbabwe have taken advantage of the increased yields of hybrid maize to make it their major cash crop. In Malawi, however, women farmers prefer local varieties of maize because of easier production and better taste. Adapted hybrids with these traits are not yet available.

Higher yields are advantageous, but secondary to these other considerations (36).

An understanding of farming household dynamics and divisions of labor—especially the key role of women—is particularly necessary when developing and promoting technology for low-resource agriculture (2,34). An urgent need exists for technologies that address women's labor constraints, yet the topic remains under-researched (8). Many cases can be found where technological innovations for women's work have excluded women, instead channeling information through male household members to the detriment of the technology's effectiveness (5,23,44).

Successful adoption of a specific technology normally will require changes throughout the farming system. For example, a small-scale irrigation scheme may only be economically feasible if there is an increase in the amount of land cultivated. This additional land could be prepared using animals, but introducing animal traction commonly requires prolonged extension efforts and may require credit that is not available. The cost of maintaining animals can be partially offset by recycling manure, but this may depend on developing improved ways of storing and transporting manure. Cultivating additional land may cause labor shortages when weeding must be done despite the use of animals; then judicious use of herbicides may be warranted. Likewise, the economic feasibility of an irrigation system could be increased by the development of farmer cooperatives. Collectivization of this sort involves its own set of repercussions. This scenario explores only a few of the many possible changes that could accompany the introduction of an irrigation scheme, but the example illustrates several points:

- Technologies are often compatible with one another—in fact, they may produce larger gains together than would be expected on the basis of the benefits of single methods.
- To make adoption of a particular technology feasible, it must sometimes be "packaged" with other technologies. However, past development efforts often failed because they presented "all or nothing" packages. Farmers unable or unwilling to adopt the entire package were not able to take advantage of a single component.
- Alternative packages consisting of various combinations of technologies are promising, allowing enough flexibility for farmers to decide which technologies to combine. Furthermore, at least some of the benefits of the package must be available immediately; they can then be used to carry the costs of the longer-term components (6).

The fact that any individual technical intervention affects, and is affected by, numerous outside factors suggests that a systems approach has the best chance of being successful. Development assistance could benefit by recognizing and planning for interactions among the various components of the agricultural system. At the same time, planners must be careful to avoid the weaknesses shown by past integrated rural development projects that attempted to be so all-encompassing that they became unmanageable.

Finding 2: To be successful given the great diversity in African farming systems, an equally diverse array of technologies adapted to local social and environmental conditions needs to exist. Although Africa will benefit from the fruits of global agricultural research, African problems will require greater attempts to develop Africa-specific solutions.

The tremendous diversity and variability in African agricultural systems is among the most challenging obstacles to technology development in Africa. Although some successes exist in promoting technologies developed outside Africa, such as the high-yielding varieties of corn that have been successfully introduced into East Africa (19), failures abound. Efforts to introduce Indian varieties of sorghum and millet into West Africa largely have failed, and after 10 years of testing at least 2,000 imported rice varieties in the mangrove swamps of West Africa only 2 have been found that perform as well as the best local varieties (29,43).

On the positive side, the diversity of farming systems represents a set of practices and resources that have evolved to meet unique local opportunities and constraints. These adapted, local practices and varieties represent a wealth of resources and information. To draw on this wealth, however, requires increased local participation. Three approaches could contribute to increased local participation:

1. **Increasing African Research Capacity Through Human and Institutional Develop**ment.—Expatriate expertise may be necessary under certain circumstances, but replacing outside expertise with trained African professionals should be an explicit objective of development assistance. It costs several times more to fund a non-African v. an African scientist in Africa given similar salary levels. Also, non-Africans take much of the knowledge of the development process with them when they leave. Therefore providing counterpart training to ensure that host country capability is developed should be a prominent objective when outside technical expertise is used. while this is a stated goal of much development assistance, in fact, expatriates play a large role in many African countries (10).

2. Improving the Links Among Researchers, Extension Agents, Farmers, and Herders.-The traditional top-down approach where technologies are developed at research stations and distributed to farms has been largely unsuccessful in Africa. Part of the problem is due to inadequacies in the extension system, but much of the failure results from attempts to distribute technologies that are not appropriate for resource-poor farmers, herders, and fishers. Improving information flow from the people to extension agents and researchers increases the likelihood that development of technologies is suited to low-resource conditions. However, even these more acceptable technologies will require improved extension systems. The ratio of extension agents to farmers, reported to be 1:3,000 for the arid and semi-arid zone of West Africa, should be increased to 1:500 to 1:1,000 according to some estimates (19,53). One possibility would be to model an agricultural extension system after the pyramid training system used in Burkina Faso to improve health care dramatically. There, a few national experts train regional trainers, who train district trainers, and soon to the village level (19). Ensuring two-way dialog in this process, as in any other extension system, should be a priority.

3. Giving Increased Emphasis to On-Farm Adaptive Research With a Farming Systems Perspective.—Initial development and preliminary field testing of a technology can benefit from the controlled conditions of a research station or closely supervised farm. However, resource-poor farmers face less than ideal conditions and adaptive research should be conducted on-farm as early as possible (box 5-2). The potential rewards available from on-farm research are substantial. Certain challenges will have to be faced, however, including:

- The high variance in environment and management present on-farm require more detailed interviews and more frequent and timely visits by the researcher compared to on-station research.
- Efforts must be made to help farmers improve their understanding of the experimental nature of the work so that farmer bias, for example, putting more labor into the trials than traditional fields, will decrease.
- Field staff must be willing to live under the less favorable conditions-of the village and be able to operate with less supervision than at the research station. An incentive system that compensates for living and working conditions off-station may be necessary (31),

Findings: Farmer and herder participation in identifying problems and acceptable solutions would enhance the effectiveness of technical assistance. Existing agricultural practices could be the starting point of a process combining the best of traditional and modern technologies.

Encouraging agriculturalists to participate in the development of agricultural technology is a way to improve the chances that innovations

Box 5-2.—Farming Systems Research

Farming Systems Research (FSR), as used in this report, refers to an approach to agricultural research and extension that emphasizes social and economic factors in addition to technical factors, including those that operate on the farm and those that are outside of, but affect the farm.' **FSR is an approach to, and not a substitute for, conventional agricultural research. It developed and continues to evolve in order to enhance the effectiveness of agricultural research, particularly in reaching resource-poor farmers.** Numerous factions exist that can be considered under the FSR rubric, but most practitioners agree that the approach relies heavily on farmer input into four stages of technology development and diffusion: (38)

1. an iterative process for diagnosing needs, problems, and constraints in the farming system;
2. identifying priority problems, analyzing proposed solutions, and developing field trials to test proposals;
3. farm-level experimentation, including monitoring, modification, and verification of proposed solutions; supportive on-station research; and evaluation of adoptability; and
4. dissemination of farmer-approved results to relevant groups of farmers.

Agricultural research and extension is more effective when an FSR component is included, but there is a cost to using FSR to support conventional research. Sociological data, for example, on intra-household dynamics and gender issues, must be collected. Anthropologists, sociologists, and economists are hired to complement the agronomists, plant breeders, and others to form multi-disciplinary teams, Some of this expense maybe reduced in the future as agronomists and other natural scientists receive training to incorporate social science perspectives more effectively into their research methodologies, There are also expenses associated with farmer participation and on-farm trials. Meaningful cost/benefit analyses do not exist yet for FSR. This is not unusual for a relatively new discipline, especially given the time-lag for the effects of agricultural research. More problematic is that as an adjunct to conventional research, FSR is difficult to evaluate independently. Many of the benefits, such as greater sensitivity on the part of researchers to the disadvantaged members of a target group, are not easily quantified.

OTA's analysis suggests that the principles embodied in FSR will be an essential component of any strategy to improve food security. This is especially true in Africa, where failure to take into account non-technical factors, such as labor bottlenecks and shortages, has repeatedly thwarted attempts to introduce technologies (33). An approach like that of FSR will be a valuable tool in helping to mitigate such factors, as well as in identifying gender, age, ethnic, and class differences that affect development assistance.

"'Farm" is used broadly to refer to the site of plant or animal production.

will be useful and acceptable and minimize the costs and time necessary for development of adapted technologies (31). Such a research partnership between scientists, farmers, and herders can be advantageous to all, as the following example illustrates.

The Variegated Grasshopper *(Zonocerus variegates)* is a widespread crop pest of the wet areas of West and West Central Africa. Western entomologists undertook a study of the *Zonocerus* problem while parallel work was done to learn the extent of local knowledge concerning this pest. Farmers understood the pest well. In fact, several farmers interviewed had anticipated the main pest control recommendation of the research team: to mark and dig up sites where grasshoppers laid eggs. These local initiatives had not yet proven very successful because they had not been coordinated community-wide. Grasshopper numbers were reduced 70 to 80 percent when the extension service provided coordination. Some discoveries made by the research team were beyond the scope of the farmers because they required laboratory facilities; for example, work on the role of the grasshoppers' chemical attractants. On the other hand, information possessed by farmers— in particular on egg-laying behavior and possible correlations between insect population and rainfall—could have sped the scientists' initial efforts and made them more cost-effective (39).

Although researchers are becoming more convinced of the advantages gained from working with farmers and herders, problems remain. The following guidelines can facilitate this process:

- Include farmers and herders as integral co-members of interdisciplinary teams. Use language and units of measure that are meaningful to them.
- Make use of their nonformal experimentation and local knowledge of soils, indigenous varieties, pests, etc.
- Encourage agriculturalists to take an active role in experiments, including making modifications and conducting evaluations.
- Reach agreement with cooperatin~ farmers about the responsibilities' for, and opportunities of, each team member (31).

Even successful traditional technologies can be improved and this approach is generally preferable to substituting foreign methods. Moreover, new technological interventions, such as fertilizers, stand a better chance of acceptance if extension plans call for their use with familiar practices, such as intercropping (growing different crops together), rather than requiring people to switch to an unfamiliar and more risky practice (e. g., monocultural farming) at the same time.

Finding 4: **Technologies in support of low-resource agriculture should reflect the high premium this approach places on risk aversion and the need to maintain flexibility in the face of environmental, social, and economic uncertainty and limited access to resources.**

Farmers throughout the world are justifiably conservative in adopting new technology when its failure could mean bankruptcy or even starvation. Resource-poor farmers and herders operate in an environment characterized by a high degree of self-reliance; they depend largely on local resources, local knowledge, and labor provided primarily by the household. Although few agricultural systems can be described as entirely subsistence, a large part of what is produced by most households is consumed by their members. The importance of ensuring adequate food supplies, especially during unfavorable periods such as during droughts, becomes of paramount importance. Many practices characteristic of low-resource agriculture ensure at least some production in bad periods, even at the expense of less than maximum yields under more favorable conditions.

To date, most agricultural research and technology has emphasized maximum production even though numerous other concerns face poor farmers, herders, and fishers. Research priorities do not yet reflect diverse objectives such as minimizing risk, reducing drudgery, and matching labor demands with labor availability. For example, even though some 80 percent of African food is grown as intercrops, in part to reduce risk, only 20 percent of International Agricultural Research Center funding for crop research involves intercrops (1,54).

Finding 5: **Resource-poor farmers, herders, and fishers rely primarily on resources internal to the farm or their immediate environment. Consequently, technologies to support low-resource agriculture also should emphasize the use of internal resources as the first step in agricultural intensification. Thorough economic analysis is needed to determine the feasibility of all technological interventions, especially those requiring externally purchased inputs.**

One way to describe the resources used in agricultural systems is as "internal" and "external" (40). Those factors internal to the farm and immediate environment include sunlight, rain, nitrogen fixed from the atmosphere, nutrients cycled up from lower soil strata and down from plant and animal wastes, and labor. External resources include purchased fertilizers, pesticides, machinery, and fuel. Information becomes an internal resource even if it is originally supplied externally. Trade-offs between external and internal resources are possible. Scientifically designed agricultural systems that attempt to decrease dependence on purchased external inputs often substitute more intensive management based on information, for example, biological knowledge of soils, crops, and animals (14).

Photo credit: Mike McGahuey

Low-resource agriculture relies primarily on internal resources such as indigenous crops and locally adapted farming methods. For example, baobab and millet are native crops in Niger and growing them together is a common practice.

Low-resource agricuhure relies largely on internal resources—many of which are renewable natural resources. By contrast, most agricultural development assistance to Africa has emphasized external resources—many of them costly and dependent on non-renewable fossil fuels. Strategies of technological intervention giving higher priority to internal resources would benefit the majority of farmers, herders, and fishers who cannot afford other options.

Family labor is one of low-resource agriculture's most valuable internal resources. Labor-efficient technologies to reduce the drudgery and overall workload, and especially seasonal labor bottlenecks, could substantially improve the lives of resource-poor farmers, herders, and fishers. Demographic, economic, cultural, and environmental factors are responsible for seasonal labor shortages (18,37) that are particularly detrimental when they result in late planting and insufficient and untimely weeding (13). However, technologies that displace labor from the rural areas may have additional adverse impacts. Most African countries do not have the industrial or non-farm employment needed to absorb rural labor.

The use of purchased inputs is feasible in several areas of Africa, and is an appropriate avenue for development assistance now. In the future, more farmers and herders can be expected to use purchased inputs, to have greater access to information, and to be better able to buy and sell their goods. While most farmers, herders, and fishers remain capital-poor, it is especially important that proposed interventions be submitted for careful cost/benefit analysis. More thorough economic analysis of all types of technologies should be an essential feature of assistance to people who already are living on the margin of survival.

Finding 6: **Development of technology with built-in flexibility and adaptability is likely to most benefit a changing Africa.**

African agriculture certainly will continue to change in the future. Strategies to improve low-resource agriculture should be designed to allow for these changes.

Development of technology that is flexible and adaptable is likely to most benefit a changing Africa. The ability to continue enhancing production is necessary to avoid stagnation of African low-resource agriculture.

Africa's rapidly growing population is one factor that will affect the future of agriculture. Another demographic shift affecting low-resource agriculture results from the disproportionate urban migration of young men in search of work. This migration creates a general trend toward an older rural population with implications for the structure of the labor force and has led to increases in the number of female-headed households. The latter is particularly important in light of the gender-based discrimination evident in areas of technology extension and credit (16).

TECHNICAL POTENTIAL FOR ENHANCINO LOW-RESOURCE AGRICULTURE

Difficulties In Evaluating Techncal Potential

The research literature on Africa is filled with promises of technological success. The International Institute of Tropical Agriculture has developed a sweet potato that can yield 40 mt/ha without fertilizers, at least six times the African average of 6.5 mt/ha (17). Windbreaks have been shown to increase crop yields, while supplying valued fodder and fuelwood. Yet the adoption rates for improved crops are very low, and freely supplied tree seedlings often go unplanted. Why? The answers range from farmer or herder unfamiliarity with the practice to researcher unfamiliarity with the farmer or herder–including researchers' failure to understand criteria used in rejecting the new technology.

Increased yields of 20 to 40 percent are typical for moderate fertilizer doses, or for plowing, or for improved land management. Yield responses of 100 percent in on-station trials are not unusual with all these improvements. Even greater increments can be attained by adding more input-responsive crop varieties. However, only a small proportion of farmers who apply these innovations approach the performance levels of experimental stations. Average yield gaps of 40 to 60 percent are normal, resulting in high risks of financial loss and low adoption rates for farmers (30).

Unlike the situation in the United States where experts can estimate increases in the national production of, for example, corn if fertilizer application is doubled, it is impossible to make a comparable continental or even national estimate for Africa. Africans' access to this input, ability to purchase it, and capability of using it effectively, are much more variable than for farmers and ranchers in developed countries. Estimates based on such a high degree of uncertainty in so many variables are problematic at best. They can be misleading and have a tendency to assume a life of their own, divorced from the caveats and cautions that originally framed them.

In some cases it is difficult, if not impossible, to use quantitative, rather than qualitative, criteria to evaluate a technology. Quarantines, for example, are intended to prevent accidental introductions of pests from outside the country. It is possible to estimate the costs incurred by a pest, such as the cassava mealybug introduced into Central and West Africa, when a quarantine fails. But methods do not exist to effectively quantify the savings that derive from successful quarantine programs.

Therefore the estimates of potential used in this report, and even the choices of technologies, are meant only to be illustrative. The technologies are not "the solutions" to Africa's problems, but are intended to suggest what might be accomplished using the approach to development assistance presented in this report. Where possible, technical benefits are evaluated based on actual use in fields, rather than at experiment stations. Rarely has OTA tried to extrapolate from these isolated examples to guessing the quantitative potential for an entire agroecological region. Benefits such as improving the stability of production have been given greater weight in this report than yield-increasing practices. Risk-aversion also has been used as an important criterion. Less emphasis has been placed on quantifying what the technology can accomplish in favor of discussing the logic of why that technology is an appropriate choice among the possible alternatives and what factors are involved in its success.

High Potential for Adoption

An important criterion in deciding which technologies can make significant contributions in Africa's future is its high probability of being adopted by resource-poor farmers, herders, or fishers. For the transfer of technologies to be successful, people must be willing and able to adopt them. Some technologies discussed in this report already are in use but are capable of improvement (e.g., intercropping). Other technologies are "new" but their acceptability is enhanced by the fact that they are well-matched to the needs and resources of low-resource agriculturalists. For example, many farmers recognize that declining soil fertility is a constraint but have found few alternatives to shifting cultivation for dealing with this problem. Many are learning the hard way that erosion hurts yields, dropping by 1 to 3 percent per year in some places (28). Alley cropping has shown potential for alleviating this farmer-identified problem. By combining scientifically based improvements for accelerating fallows with other benefits such as fuelwood and fodder production, alley cropping represents an affordable technology that addresses several farmer concerns.

Too often technologies have been evaluated on the basis of their technical qualities, with too little attention paid to whether they will, or can, be used. Furthermore, even when a technology has been used successfully in one case, its feasibility under different locale-specific conditions must be evaluated. For example, animal traction has been shown to be advantageous in Africa and could receive increased attention from development assistance. However, many animal traction technology packages require that new kinds of cattle be purchased and kept well-nourished and disease-free. The low adoption rate of this technology among resource-poor farmers will persist unless prerequisites to adoption are addressed—e.g., availability of forage supplies, veterinary care, and extension information about the benefits of unfamiliar types of animals.

Potential to Modernize Gradually

Another advantage of the technologies discussed in this report is that they do not lock people out of modern agriculture. For example, soil and water conservation practices can produce benefits alone, but they bring added benefits when commercial fertilizers are also used (30). Conservation practices can improve soil structure and increase soil organic matter. At the same time, they can slow water run-off and leaching below plant root zones and thus prevent fertilizers from being washed away. The mutually supportive effect of technologies—for example, using tied ridges and fertilizer—can be significant (table 5-2). The higher yields that result can offset the cost of introducing other technology (e.g., animal traction and irrigation) that allow the farmer to cultivate a larger area or extend the growing season.

The time frame for adoption of technological innovations will vary considerably across Africa based on agroecological factors and on the differing rates at which transitions to more intensive systems are possible, given socioeconomic conditions. Sequential changes to farming and herding technology are likely to be important. For example, resource-poor farmers and herders in semi-arid regions maybe most able to adopt technologies in this sequence:

1. water-harvesting or run-off/erosion management systems,
2. increased use of organic fertilizer,
3. introduction of chemical fertilizers, then
4. introduction of improved cultivars (29b).

Each stage provides its own benefits and reduces the risk and increases the returns to the changes involved in the next stage. This type of sequencing may provide the most practical and cost-effective means of introducing packages of inputs. Sequencing also allows researchers and extension agents to focus their efforts more narrowly and farmers may be more likely to adopt new methods for the same reason. In sum, the sequential introduction of technology in support of low-resource agriculture may best be viewed as a natural evolution toward increased input use, but at a pace consistent with the highly variable agroecological and socioeconomic conditions in the region (29b).

Technology-Specific Potentials

The technologies discussed here have additional benefits, depending upon their specific characteristics. The following sections highlight that potential, summarizing information presented in more detail later in this report.

Table 5-2.—Economic Analysis of Farmer-Managed Trials of Sorghum With Fertilizer and Tied Ridges at Nedogo- and Diapangou, Burkina Faso in 1983 and 1984

	Treatments[a]			
	c	TR	F	TR,F
		Nedogo: 1984, manual traction		
Grain yield, kg/ha[b]	157	416	431	652
Yield gain above control, kg/ha	—	259	274	495
Gain in net revenue, FCFA/ha[c]	—	23,828	13,275	33,607
Return/hr of additional labor, FCFA[d]	—	238	140	172
°/o farmers who would have lost cash	—	o	27	9
		Nedogo: 1983, manual traction		
Grain yield, kg/ha	430	484	547	851
Yield gain above control, kg/ha	—	54	117	421
Gain in net revenue, FCFA/ha	—	3,510	–2,285	17,475
Return/hr of additional labor, FCFA	—	35	—	90
°/o farmers who would have lost cash	—	o	66	0
		Diapangou: 1984, donkey traction		
Grain yield, kg/ha	498	688	849	1,133
Yield gain above control, kg/ha	—	190	351	635
Gain in net revenue, FCFA/ha	—	17,480	20,359	46,487
Return/hr of additional labor, FCFA	—	233	214	273
°/o Farmers who would have lost cash	—	o	21	0
		Diapangou: 1983, donkey traction		
Grain yield, kg/ha	481	522	837	871
Yield gain above control, kg/ha	—	71	356	390
Gain in net revenue, FCFA/ha	—	6,532	20,819	23,947
Return/hr of additional labor, FCFA	–	87	219	141
°/o farmers who would have lost cash	—	o	16	12

aC = Control (no tied ridges or fertilizer); TR = tied ridges constructed at second weeding; F = fertilizer: 100 kg/ha; 14-23-15 applied in band 10-15 cm from row at first weeding plus 50 kg/ha urea applied in pockets 10-15 cm from seed pockets at second weeding.

bThe standard error and coefficient of variation (in percent) (in parentheses) starting with Nedogo, 1984 and continuing through to Diapangou, 1983 are 75 (43), 121 (29), 46 (18), and 43 (22), respectively.

CNet Revenue = yield gain X grain price (65 and 92 FCFA/kg in 1983 and 1984) minus fertilizer cost (62 and 78 FCFA/kg for 14-23-15, and 60 and 66 FCFA/kg for urea in 1983 and 1984-fertilizer prices are subsidized 40 to 50 percent). Includes interest rate charge for Six months at rate of 15 percent. 1 U.S. dollar = 381 FCFA in 1983 and 436 FCFA in 1964.

dNet Revenue—additional labor of tied ridging and fertilizer application. Manual and donkey traction require 100 and 75 hours of additional labor/ha for tied ridging respectively Fertilizer application requires 95 additional hours/ha.

SOURCE: Purdue University, International Programs in Agriculture, *Cereal Technology Develpment-West African Semi-Arid Tropics: A Farming Systems Perspective,* final project report for the U.S. Agency for International Development (West Lafayette, IN: 1987).

Potential Based on Improved Use of Natural Resources

Many experts believe that conserving and regenerating the natural resource base must become one of the highest priorities for the technical component of development assistance to Africa. Resource-poor farmers and herders depend on the land to supply life's basic requirements—food, fuel, fodder, and a safe and reliable water supply. Production can be increased and stabilized by more efficiently using existing resources. FAO has conducted some 55,000 technology demonstrations in Africa since 1961, covering improved management practices, improved crop varieties, and pest control. These trials show that improved management practices alone can raise yields 20 to 80 percent (tables 5-3 and 5-4). FAO estimates that full use of conservation measures, without changing crops or levels of inputs, could increase long-term land productivity for low-input agriculture by 33 percent (46).

Failing to undertake this work will have substantial costs. For example, soil erosion leads to loss of soil organic matter, which is necessary for plant growth because it improves soil structure, fertility and water availability. At least 25 mil1ion hectares in Africa's humid lowlands, subhumid tropical uplands, and tropical and subtropical highlands are subject to

Table 5-3.—Effect of Improved Practices, With and Without Fertilizers, on Crop Yields[a]

Country/zone	Crop	National average yield	Yield with improved practices	Yield with improved practices and fertilizer
Burkina Faso (Sudano-Sahelian Africa) . . .	Millet	430	520	1160
Cameroon (humid Central Africa)	Rice	840	1360	2500
Ethiopia (sub-humid and highland East Africa)	Maize	1100	2010	4100

aYield in kilograms per hectare.

bThese represent gains that can be achieved through improvements in management practices collectively. Table 5-4 shows the gains from the individual practices.

SOURCE: U.N. Food and Agriculture Organization, *Africa Agriculture: The Next 25 Years, Annex ///: Raising Productivity* **(Rome: 1986).**

Table 5-4.—Gains From Improved Management Practices

Soil and water conservation	10 to 50%
Seed bed preparation	10 to 25°/0
Time of planting	10 to 50°/0
Plant population density	10 to 20°/0
Seed treatment	5 to 10%
Weeding	10 to 50°/0

SOURCE: Food and Agriculture Organization of the United Nations, *Africa Agriculture: The Next 25 Years, Annex ///: Raising Productivity* **(Rome: FAO, 1986).**

extensive soil erosion, and even arid areas face serious risks during seasonal torrential rains (48). Long-term declines of agricultural productivity due to land degradation, mainly soil erosion, could be severe. FAO estimates that Africa could lose 16.5 percent of its rainfed cropland if degradation goes unchecked. Declines in land productivity could reach 25 percent due to losses in soil fertility, even accounting for some livestock production on degraded cropland (46).

Many technologies discussed in chapter 7 can reduce this problem. For example, terraces are a well-documented method that can virtually eliminate soil erosion caused by water run-off. Increases of 50 percent in maize production have been attributed to their use in the Kenyan Highlands (25). Windbreaks can effectively reduce wind erosion of soils, as well as protect young crop seedlings from wind abrasion. In one of the largest coordinated projects of its kind, the Majjia Valley windbreak Project in Niger has resulted in average crop yield increases of some 20 percent on fields between windbreaks (9).

Potential Based on Improving Soil Fertility

Several technologies—minimum tillage, mulching, manuring, and agroforestry—improve soil fertility not only by reducing soil erosion, but by directly adding organic matter to soil. These types of technologies that improve soil fertility merit attention because they maximize the contribution of renewable resources and because of their low cost and accessibility. For instance, a substantial amount of nitrogen is already supplied by legumes and this contribution can be increased significantly by increasing their use in agroforestry, intercrops, and crop rotations. *Acacia albida,* an indigenous leguminous tree commonly intercropped with millet, sorghum, or groundnut, consistently increases the yield of the annual crops. In one documented case, millet and groundnut yields on infertile soils rose from 500 kg/ha to 900 kg/ha when grown with *Acacias (12).* Maize yields stabilized at about 2 tons/ha after 6 years of continuous alley cropping with leguminous trees, compared to no more than 0.5 ton/ha without alley cropping (22).

It is difficult to extrapolate legumes' potential contribution to production in Africa from these research results, Legumes probably cannot suply all the nitrogen necessary to grow enough food to feed Africa's current population, much less the additional people expected by the year 2000. But it is clear that legumes can make a significant, affordable contribution to Africa's forage and soil nitrogen needs. No more than 100 years ago, crop rotation with legumes was the principal means of restoring soil fertility intemperate zone agriculture. Now, it is an effective source of nitrogen used on numerous low-input farms that have developed in the United States during the last two decades. Africans have not had to rely on this deliberate use of legumes because shifting cultivation was an equally effective method of restoring soil fertility. Legumes were often a naturally occurring component of this process. The reintroduction of legumes into African agricultural systems could partially compensate for shortened fallows now.

Inorganic fertilizers will have an extremely important role in Africa's agricultural future, but they are likely first to supplement—not substitute for—organic fertilizers. As has been the case wherever they have been introduced, inorganic fertilizers will be used as they become available. Availability includes not only that they be affordable, but that their access be dependable and timely. Where adequate roads and markets exist for distribution and trained people for research and extension, as in Zimbabwe, commercial fertilizers are widely adopted and the benefits are impressive. Until the rest of Africa reaches this stage of development, however, the whole range of other fertility-enhancing technologies is likely to have high potential in many areas.

Potential Based on Improving Water Availability

Efforts to improve water use could first be directed at making more efficient use of freely supplied rainwater rather than relying on purchased inputs. For instance, recession farming (also called flood farming) is a high-productivity traditional practice used along major rivers of Africa. However, as dams become more common the traditional use of this technique is not possible unless special provisions are made. A proposal has been made to include a controlled, artificial flood as part of the plans for an irrigation project along the Senegal River. It remains to be seen whether such controlled flooding will allow farmers to reap the benefits of recession farming without interfering with dam operations.

Contour planting, water harvesting microcatchments, and tied ridges are all methods shown to be effective for improving rainfed agriculture under appropriate conditions. In most years these practices bring only slight yield increases. Their biggest advantages are realized during drought years, when improved fields are able to maintain yield levels while other fields experience crop failures (7,35). FAO estimates that low-cost technologies such as these can significantly improve at least 50 million hectares of arable land in subhumid and semi-arid Africa (48).

Unlike the technologies mentioned above, which in some ways are alternatives to irrigation, other practices exist that improve the efficiency of water use whether the source of the water is rain or irrigation. Technologies such as minimum tillage, mulching, and applying manure, increase infiltration rates as they improve soil quality, thereby increasing the amount of water that remains available for plant growth. Assistance to develop these practices is warranted even if they were evaluated simply for the contribution they can make to rainfed agriculture. But, in fact, they will be equally important in facilitating the transition to a more intensified agriculture that may include irrigation.

The technical benefits from small-scale irrigation, especially water pumping, are substantial and offer hope for overcoming the vagaries of an African climate notorious for erratic and often insufficient water supply. However, serious obstacles exist to wider implementation of irrigation technologies, and FAO, among others, estimates that increases in irrigation—large- or small-scale-will be minor for the foreseeable future (49). Adoption of small-scale irrigation technology will be a difficult and slow process.

Potential Based on Genetic Improvements

Crop and livestock breeding can be expected to make a larger contribution to agricultural development in the future than it has up to now. For example, new improved crop varieties exist that are able to yield more and do so on a more reliable basis because of their resistance to major pests and diseases and their greater tolerance to drought and other environmental stresses. Dramatic increases in milk production have been possible in some regions by crossing African cattle breeds with exotic dairy breeds.

Based on agricultural developments outside of Africa, and preliminary accomplishments within Africa, research to improve crops through genetics represents one of the best investments for supporting low-resource agriculture. This is less true for livestock breeding, however, where improved management (e.g., attention to nutrition, disease, and climatic stress) is a prerequisite to gains through genetic improvement. Plant breeding, however, may increase animal productivity given the increasing use of crop residues as animal fodder.

The yield increases obtained in plant and animal breeding research can be dramatic, but they seldom have been realized by farmers and herders when conditions are less favorable. The gap between results achieved on-station and on-farm will be reduced as decreased emphasis is placed on breeding materials suited for actual conditions.

Photo credit: J. Van Acker/U.N. Food and Agriculture Organization

Considerable potential exists to enhance low-resource agriculture by making genetic improvements in crops and livestock and by better integrating animal and cropping systems.

Potential Based on Improved Integration of Animal and Cropping Systems

The integration of animals into cropping systems is expected to increase as techniques such as fodder banks and alley cropping enable farmers to maintain animals more readily. Livestock make numerous contributions to food security needs, including: providing milk and meat, and acting as food reserves; providing a source of income, savings for emergencies, and export earnings; and providing animal traction. Small ruminants (e.g., goats and sheep), in particular, have been neglected by development assistance but could become more important in the future.

Animal traction allows more land to be cultivated and it becomes more cost-effective when crops can generate cash, which can then be used to repay loans for purchasing and maintaining the animals as well as purchasing other inputs. Present rates of return can be doubled and tripled as animal power becomes available for weeding and other farming activities, rather than just for plowing. For example, weeding, which is a major labor bottleneck for most farmers, can be performed six times faster with animal traction. Better adapted implements will assist in this process, but other constraints are farmer unfamiliarity and the initial expense of purchasing animals. Extension will be instrumental to enable farmers to take advantage of animal traction for a variety of farming activities (20).

Aquiculture can contribute to food security by supplying high protein food and by generating income to purchase food. Farm by-products, such as animal manure and crop residues, can be used to stimulate fish production from aquiculture. Enriched pond water can be used to irrigate home gardens, completing the recycling process.

Potential for Reducing Food Losses

Integrated Pest Management (IPM), using the best mix of available pest control methods, can significantly reduce field losses in a cost-effective, sustainable, and safe manner. Human and environmental health is improved because 1PM emphasizes only judicious application of pesticides in conjunction with other pest control practices, rather than relying on pesticides alone, The objective of 1PM is to reduce pests to an acceptable level rather than trying to eradicate them altogether.

Post-harvest losses also can be reduced, using technologies adapted to the socioeconomic and environmental features of the farming system. Perhaps more important than the food saved are the labor savings. Improved technologies exist that can reduce labor needs and make operations more efficient. Women, who have primary responsibility for post-harvest activities, are the main beneficiaries, with subsequent benefits accruing to the whole household,

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