Chapter 9

Crop and Livestock **Genetic Improvement**

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Chapter 9

Crop and Livestock Genetic Improvement

SUMMARY

Historically, agriculture has benefited from and relied on breeding and genetic adaptation to improve crops and livestock. For some 10,000 years, farmers and herders have selectively chosen offspring from those plants and animals that performed well. In time, breeding became a highly sophisticated science. Eventually, agriculture evolved from choosing the most appropriate crops and animals for the environment to altering the environment to improve animal and plant growth and nutrition.

Low-resource farmers and herders have developed considerable expertise in the manipulation of agricultural environments to enhance and stabilize plant production. These activities primarily involve adapting micro-environments to their needs through such practices as shading, mulching, and wind protection (43). Farmers also engage in some of the steps in plant breeding, making selections within plant varieties in order to take advantage of differing micro-environments (e.g., type or moisture content of soil). This process of fine-tuning varieties to local environments, is largely responsible for the high degree of genetic diversity in traditional varieties and landraces (see box 9-1).

Box 9-1.—Definitions of Common Breeding Terms

Local varieties or breeds (also called traditional varieties or landraces): All varieties and breeds that are grown today, even in the most isolated areas of the world, have benefited from continuous selection by farmers and herders. Local ones, however, are considered "unimproved" to contrast them to those that have been "improved" by modern scientific research.

Improved varieties or breeds: Varieties and breeds developed through scientific research. One major difference between improved and local varieties and breeds is that the former have more identifiable and uniform traits, which can be replicated more closely.

Open-pollinated improved varieties: A subset of improved crop varieties distinguished from hybrids in that the farmer is able to set aside some of the harvest to use as seed the following year. The technique for developing these varieties generally consists of bringing together a gene pool of varieties within which most of the desired traits are represented, and upgrading the uniformity and level of performance of the pool by systematic selection.

Hybrids: Hybrids are a subset of improved crop varieties that result from crossing separate pure lines. Improvements typically are much greater than for other improved varieties, but because they do not retain their superior performance in subsequent seasons, new seeds must be bought each year in contrast to open-pollinated varieties.

HYVs: High yielding varieties are another subset of improved varieties. HYVs are bred to respond to increased inputs and are typically short-stemmed, allowing them to produce more grain without tipping over. When crop plants fall they become more difficult to harvest and more susceptible to pests and diseases. HYVs, associated with the Green Revolution, were bred to take advantage of irrigation and fertilizer.

Crossbreeding: Any livestock improvement system that aims to exploit the complementarity between two distinct breeds or varieties.

With the advent of new agricultural technologies and inputs, the balance between adapting varieties to suit the environment v. adapting environments to suit the varieties shifted heavily toward the latter. Far greater manipulation of the environment was undertaken, such as wide-scale regulation of water, nutrients, and pest populations. The shift is best illustrated by the Green Revolution technologies, where the performance of high-yielding varieties (HYVs) were predicated on extensive use of irrigation, fertilizers, and pesticides. Equivalents in the area of livestock development included veterinary intervention or disease eradication programs to enable higher producing breeds to survive where they previously could not.

Disappointing results in Africa's ability to benefit from these Green Revolution technologies has led to reexamination of strategies for increasing crop and livestock productivity in African farming systems—in particular crop and livestock breeding. Africa has been largely bypassed by the Green Revolution as well as by more conventional plant and animal breeding (9,10) (table 9-1). Much of the continent has low water availability, infertile soils, and severe pest and disease problems. Except for restricted cases, institutional and economic limitations prevent the use of the Green Revolution technology packages designed to compensate for these serious environmental constraints. Only about 1 percent of Africa's cereal farmland is used to grow high-yielding varieties, and only about 10 percent is growing improved varieties (48,59). A similar situation exists for animal breeding, which has had little impact on resource-poor farmers and herders in Africa.

Breeding, however, can be expected to make a major contribution to agricultural development in the future. For example, new improved crop varieties exist that can reliably increase yields because of their resistance to major pests and diseases. Dramatic increases in milk production have been made possible in some favorable regions by crossing African breeds with exotic dairy breeds. Based on agricultural development outside of Africa, and preliminary accomplishments within Africa, research to improve crops through genetic improvement represents one of the best investments for enhancing low-resource agriculture. This is less true for livestock, however, where improved management (e.g., attention to nutrition, disease, and climatic stress) is a prerequisite to gains through genetic improvement (6). Goats and sheep, however, show considerably greater promise than cattle (33).

Realizing the full potential possible from genetic improvements will require changes in many segments of the agricultural economy, such as improving incentives for farmers and herders to increase production, and making it more cost-effective to adopt improved varieties. Several necessary changes closely related to breeding include:

- decreasing the wide gap that currently exists between on-station and on-farm results,

Table 9-1.–Grain Yield Per Hectare by Region, 1950-52 and 1980-82

Region	Average annual yield (kg) 1950-52	1980-82	Change (percent)
North America	1,646	3,757	+ 128
Western Europe	1,733	3,843	+ 122
East Asia	1,419	2,973	+ 109
Eastern Europe	931	1,819	+ 95
South Asia	825	1,450	+ 76
South America	1,217	1,854	+ 52
Africa	**757**	**1,044**	**+ 38**
Australia*	**1,100**	**1,301**	**+ 18**
World	**1,186**	**2,247**	**+ 89**

"Data are for 1981-83.

SOURCE: U.S. Department of Agriculture, Economic Research, *World* Indices of Agricultural *and* Food Production, 1950-1983, unpub. printout (Washington, DC, 1984), cited in L. Brown and T. Wolf, *Reversing Africa's Decline* (Washington, DC: Worldwatch Institute, 1985).

- **choosing appropriate breeding strategies that more closely reflect the conditions and potentials of low-resource farmers and herders,**
- **establishing a better match between research funding for agricultural commodities and their importance for Africa's food security, and**
- **addressing needs for improved seed multiplication and distribution.**

Several factors restricting wider use of improved varieties, for example, poor transportation and marketing infrastructure, will require a long time to resolve. In the meantime, affordable, immediate, and significant advances can be obtained by improving agronomic and livestock management practices for traditional or improved varieties [4,14,34,57). Since inefficient practices sometimes are the limiting factors, improvements in them may outweigh those from plant or animal breeding. Even so, the gains resulting from the use of these improved practices for improved varieties typically are greater than for local varieties.

CROP BREEDING[1]

Crop breeding is the process of selecting traits from parent plants to produce offspring that are "better" according to some predetermined criteria. The most important objectives for crop breeding for resource-poor farmers in Africa include:

- higher yielding under farmer conditions;
- yield stability from season to season;
- pest and disease resistance;
- tolerance to environmental stress;
- improved quality, storage, and ease of processing; and
- adaptation to diverse cropping systems, including intercropping.

Breeding objectives may differ according to clientele. A variety used primarily for home consumption (often grown by women) would probably concentrate on yield stability, storage and processing characteristics, and nutritional quality. When breeding a variety for cash generation (often produced by men), it maybe more appropriate to emphasize responsiveness to management and inputs.

Maintenance research is necessary to sustain breeding improvements and it can require as much money and time as it took to develop the improvements initially (39). Also, when an improved variety is introduced into a new environment, a minor pest may cause unanticipated damage, necessitating additional research to improve host resistance.

The Potential of specific African Crops[2]

Millet

Millet is grown on 15.5 million hectares in Africa, producing 8.8 million metric tons of food grains per year (47). Although it is often grown with sorghum in the arid/semi-arid zone, millet can be produced in areas too dry even for sorghum. Two species–pearl or bulrush millet *(Pennisetum americanum)* and finger millet (Eleusine coracana)—native to Africa account for 95 percent of production, the former being about four times as prevalent. pearl millet is the only major food crop that can be grown on the sandy soils from Senegal to Sudan. It is also grown in the drier areas of eastern and southern Africa, but production there is only one-fifth that in West Africa. In contrast, fin-

[1]This material on crop breeding is based primarily on OTA contractor reports prepared by David J. Andrews, University of Nebraska, Lincoln, NE; Fred R. Miller and John A. Mann, Texas A&M University, College Station, TX; Sherman F. Pasley, University of Florida, Gainesville, FL; Ivan W.Buddenhagen, University of California, Davis, CA; Walter A. Hill and Conrad Bonsi, Tuskegee University, Tuskegee, AL (app. A).

[2]Where the potential of improved varieties is discussed, it is based on estimates of crop breeders contacted by OTA, and data on current yields from the U.N. Food and Agriculture Organization (FAO). Estimates assume the use of improved seeds and improved management practices. These discussions are often framed around yield enhancement, but it is important to note that these yield estimates take into account improvements that also reduce losses to pests, drought, etc.

ger millet is grown in the moister areas of eastern and southern Africa, principally in Kenya, Uganda, Tanzania, Malawi, Zaire, Zambia, and Zimbabwe (40). Alternative crops such as sorghum and maize are also commonly grown in these moister areas.

Other African millet species are of restricted local importance; for example, "Iburua" or "Fonio" *(Digitaria iburua)* is an important famine food in several west African countries and "Tef *(Eragrostis tef)* production is about 145,000 tons/year in Ethiopia.

Millet production currently averages about 500 to 700 kg/ha/yr but this could be doubled in 20 years by a combination of new varieties and improved cultivation practices (4). Convincing theoretical, experimental, and on-farm evidence exists to support such claims (16).

Genetic improvement could increase yields by perhaps 1 percent per year. Yield potential in unimproved varieties exceeds 3 tons/ha/yr (28,29). Currently, however, these landraces produce a low proportion of grain compared to total plant biomass, therefore much of the breeding effort is directed to improving this ratio. Higher yielding and disease-resistant varieties of pearl millet are now grown on half of India's 11 million hectares. Yield increases of 20 percent were obtained over the last 2 decades from crosses between African germplasm and Indian breeder stocks. Similar sources of variability also have great potential in Africa but are more difficult to exploit because Africa faces greater disease and pest problems.

A number of improved varieties have been released in Africa, but widespread adoption of these varieties has not occurred. However, the precise extent of adoption is not well-documented and the degree of farmer-to-farmer spread not known. It is doubtful that more than 10 percent of any African country's cropland is planted in improved varieties, although this figure may be higher in Senegal (4).

On-farm evidence shows that large differences in yield exist between adjacent fields belonging to different farmers. Since both receive the same rainfall, the major difference is attributed to management and previous cropping history. The best fields in a given locality already are giving double the average yield. Many agronomists agree that low soil fertility and inadequate, untimely management, not crop-water availability, are currently the major on-farm factors restricting production (16).

Sorghum

Sorghum evolved in north-eastern Africa some 2,000 to 4,000 years ago. The sorghum belt extends from approximately 7 to 15 degrees north latitude from the west coast to the east coast. It is the primary source of dietary energy for the majority of the region's poorest people.

Although sorghum is thought of as a crop for arid and semi-arid regions, it is also important in some wetter areas: the highlands of East Africa from Ethiopia to Burundi and Rwanda; semi-humid areas of West Kenya and Uganda; and in areas of the Guinea Savanna in West Africa. It is the first or second most important cereal grain in much of Africa, sharing importance with millet throughout the arid/semi-arid zone and with maize in the wetter areas.

Sorghum breeding is an art as old as the crop, but rather young in terms of modern science. The germplasm base is extremely broad, but still vastly underused, and since sorghum is of African origin, Africa stands to benefit greatly from additional research.

Plant breeders do not agree on the extent to which current sorghum yields can be increased. Part of the disagreement arises because the estimates are derived from different starting points —sorghum is grown under a wide range of environmental and management-intensive conditions. Based on a weighted average of U.N. Food and Agriculture Organization data for Sub-Saharan Africa, the average yield for sorghum is 780 kg/ha/yr (49). productivity in Sudan is about 20 percent lower than the average, while neighboring Ethiopia averages 1,350 kg/ha/yr (49). Gains of between 50 and 100 percent are possible on fertile soils with moderate rainfall simply by using existing improved varieties (34). The 100 percent estimate, a doubling of the current level, assumes 10 to 15 years of additional

Photo credit: Dale Bottrell/Consortium for International Crop Protection

Sorghum is an important cereal grain in most of Africa and its growers stand to benefit greatly from improved varieties.

successful breeding improvements. Related improvements in management could result in yields of 4,000 to 8,000 kg/ha/yr in areas of reasonably good soil conditions, with yields reaching half this level on the acid soils of Mali, Niger, and much of West Africa (34). Other researchers are less optimistic, perhaps because their focus is on the difficulty of extending the entire package which consists of the new variety, new management practices, and increased use of inputs such as fertilizer. These more pessimistic views place possible production levels at between 1,500 to 3,000 kg/halyr using improved varieties and management practices (3,32,41).

Sorghum hybrids are uncommon except in Sudan and Zimbabwe. The adoption rate for hybrids and other improved varieties in most of East Africa is only 5 to 10 percent, and it is even lower in West Africa (34). Some crop breeders believe that hybrid sorghum is appropriate only for a small area of Africa, and that research and extension efforts should reflect this, placing increased emphasis on improving non-hybrid sorghum varieties for most of Africa (34).

Maize

Maize, although not native to Africa, is planted on more land than any other cereal (56), and it is undoubtedly the most important grain in the subhumid tropical uplands and the highlands. Its ecological requirements overlap considerably with sorghum, but it is not as drought tolerant. Maize consumption tended to be restricted to urban areas in the past, perhaps because of food aid and imports. Increasingly, however, maize is becoming more widespread, a trend that is likely to continue given its productivity.

Maize yields in different African countries vary dramatically but the average is 1,160 kg/ha/yr (49). Countries that do not make wide use of improved seed typically average 600 to 700 kg/ha/yr, whereas in Zimbabwe where improved seeds are used the average is nearly three times higher (49). Estimating the potential increases in yield for low-resource farmers is difficult, however. Adoption rates for improved maize are generally high, so maize yields could double in many areas in the near future (17,38). The continued spread of hybrids that began in the mid-1960s should allow even greater increases (56,60). The area planted to hybrids in Kenya, Zimbabwe, and Zambia is exceptionally high, and can be attributed to the advanced infrastructure, incentives, and inputs that favor the use of improved maize in these countries. The estimated amount of land in Africa now devoted to Kenyan and Zimbabwean improved maize varieties could be doubled (49).

Nigeria is making extensive use of disease-resistant maize materials developed by the International Institute of Tropical Agriculture. In addition, recently developed Tanzanian and Zambian varieties and hybrids are streak-virus resistant and will be useful in large areas in neighboring countries (17). Breeders have had little success in increasing maize tolerance to drought, but several improved varieties mature more quickly than local varieties and, therefore, are less affected by the onset of the dry season.

Rico

Two species of rice are grown in Africa: Asian rice *(Oryza sativa),* which was introduced, and African rice *(Oryza glaberrima).* Rice is the fourth most common crop in Africa in terms of hectarage after maize, millet, and sorghum (56). It is grown throughout Africa wherever water is adequate, including river basins within the arid and semi-arid zone. However, it is a major food crop of only a few African countries.

Three major forms of rice cultivation can be distinguished for Africa: dryland, wetland, and irrigated. Dryland (or upland) cultivation is practiced where rain is the only source of water. It comprises about 40 percent of the paddy production in Sub-Saharan Africa's 15 major rice-producing countries. Wetland cultivation (e.g., in swamps, mangroves, and deep water) occurs in all four major agroecological zones and represents about 45 percent of paddy production. Only about one-sixth of the region's rice is produced using modern irrigation and, 60 percent of this occurs in just one country—Madagascar (51).

Dryland rice, which occupies about half the area planted to rice in Africa, is low yielding and depresses the 1,450 kg/ha annual average for rice in Africa (49). Some improvements have been bred into dryland varieties (60), and additional research emphasizing disease resistance is justified. Greater potential exists, however, for improving rice production in other agroecological zones (7). High-yielding varieties are used on approximately 4.7 percent of the area planted to rice (9). For these rice production systems, as for dryland rice production, breeding for disease resistance is important.

Yields could be increased in many areas by improving water control, but significant problems hinder irrigation in Africa (see ch. 7). Expansion into wetland areas offers the greatest potential for production increases. However, current rice improvement efforts for Africa do not reflect this (7).

Food Legumes

A diverse group of legumes are grown as crops in Africa, including cowpeas, common beans, lima beans, soybeans, groundnuts (peanuts), bambarra groundnuts, pigeon peas, chickpeas, and a number of other minor species. One or more legumes grow in each agroecological zone, and many of these crops can be grown under a wide range of ecological conditions. Bambara groundnut, for example, is one of the most drought-tolerant legumes, but it also grows in the rainforest environment and in cool, moist highlands. Typical of other food legumes, this crop contains two to three times more protein than cereals, yet it is considered a "poor people's crop" and is among the most neglected by science (35). Legumes are also valuable sources of oil, and are important in animal nutrition.

Many legumes are able to fix nitrogen and, therefore, can thrive in nitrogen-poor soils. This ability makes them well-suited to crop rotations and enhances their benefits in intercrop situations.

The major research emphasis has been and should continue to be stabilization of production through increased disease and pest resistance, development of short-cycle varieties, such as the 60-day cowpea variety developed by the International Institute of Tropical Agriculture, and improved nitrogen-fixing ability. Major advances in yield potential maybe possible, but will be secondary to these other considerations (7). Potential also exists for expanding the use of legumes into new areas; for instance, lima beans could be introduced to the seasonally or continuously humid tropics, pigeon peas could be used in the arid/semi-arid zone, and chickpeas could be grown in the highlands.

Roots, Tubers, and Plantains

Root and tuber crops are major sources of food energy for at least 200 million people in Sub-Saharan Africa, particularly in the humid and highland areas (5). For example, they account for at least half the calories in people's diets of Zaire, Congo, and Gabon (56). Many of these crops are efficient producers of calories, much more so than maize on a per-hectare basis. For example, compared to maize, cassava produces 2.2 times as many calories/ha; yams produce 2.7 times as much; and sweet potato produces 1.5 times as much (52).

Cassava (Manihot esculentum) is the most widely grown root crop, and it is adaptable to a wide range of agro-climatic and soil conditions. It is able to survive on marginal soil and so is often grown as the last crop in a rotation sequence, before the land must be abandoned to fallow. Even though it can be grown under humid conditions, cassava is fairly drought tolerant (20). Cassava accounts for approximately one-third of the total staple foods produced in Africa and its leaves are a preferred green vegetable that provide high-quality protein, minerals, and vitamins (52). It can be stored in the ground safely for up to 36 months, thus making it available to farmers anytime of year (18).

The tolerance of cassava to extreme stress, its efficient production of calories despite low-resource requirements, and its year-long availability and compatibility with other crops will continue to make cassava an important component of diversified farming systems (20). Cassava yields in Africa average 6.4 t/ha/yr, compared to the world average of 8.8 t/ha/yr (19). Improved varieties exist that are high-yielding, resistant to disease and insect pests, good quality for consumer acceptance, and low in cyanide content. The amount of land planted with these improved varieties is still very low in Africa, but their use is increasing as evidenced in Nigeria (22).

Yam (Dioscorea spp.) requires fertile soils and is produced chiefly in the more humid countries of West Africa. Africa produces an estimated 96 percent of the world's yams, concentrated in Africa's "yam zone:" Nigeria, Benin, Togo, Cameroon, Ghana, and the Ivory Coast (18). Despite the high labor cost to produce yams, it is a preferred food in these countries, a highly valued cash crop, and an important source of income for resource-poor farmers (22). Although almost all yams produced are local varieties, adoption of improved varieties may spread with the help of a recently developed method of producing "seed" yam (conventional tubers used for planting weigh about 800 grams, whereas the new ones weigh about 30 grams). The "minisett technology," as the International Institute of Tropical Agriculture has labeled this breakthrough, can increase the amount of planting material available, shorten the period during which the land is occupied with yams, and allow for healthier plants and more uniform stands. The end result has been higher yields and economic returns (5].

Sweet potato (Ipomea *batatas)* is grown through out Sub-Saharan Africa, but is a major staple in only a few countries: Burundi, Rwanda, and Uganda. Although it grows well under a variety of ecological conditions, its sweetness limits its acceptability (22). As with cassava, the crop can be used for animal feed as well as human consumption. Improved **sweet** potato varieties exist that are resistant to weevil, disease, and nematodes, but adoption rates remain low (22,25].

Aroids such as cocoyams *(Xanthosoma spp.* and *Colocasia spp.)* require an ample water supply and, thus, tend to be concentrated in areas of high rainfall. They are important in four of the humid countries: Cameroon, Ghana, Gabon, and Nigeria (52). Although several clones of cocoyam resistant to diseases have been identified and are being incorporated into breeding programs, virtually no improved varieties are being used by farmers (22).

plantains also are widely grown, particularly in forest areas and in home gardens. They are a major energy source in a few rural areas such as those in Rwanda and Uganda. Plantains are an ideal crop to raise following forest clearing because they need little land preparation and they provide useful cover within intercrops. Plantains can be grown on steep slopes unsuited to root crops and cereals (52).

Although cassava can be stored underground, most root, tuber, and plantain crops are difficult to store. In terms of production, yield enhancements are most likely from efforts directed at increasing pest and disease resistance. Improvements in quality, for example, reducing the cyanide content of cassava and the sugar level in sweet potatoes, is another promising avenue for plant breeding (22).

Potential of Crop Brooding

The genetic code carried in the seed is especially valuable to the farmer with limited resources, since this is potentially one of the least expensive inputs that can be purchased for a large area (15).

The potential benefits to resource-poor farmers in Africa from crop breeding are high. Improved varieties offer a relatively inexpensive way to improve productivity markedly (4,15). A combination of factors are beginning to offer hope for higher, more stable yields: resistance to several pests and diseases has been bred into many major crops; new crops can make more efficient use of internal and external resources; and more quickly maturing varieties allow additional flexibility in crop rotations and increased stability under variable and often adverse climatic conditions. New priorities in research, if they can be fostered, could lead to substantial improvements in food quality, processing, and storage.

Significant improvements can be expected to result from breeding because comparatively little research has been done on African crops, so the potential seems virtually untapped. Landraces—unimproved varieties now in use—are well adapted to produce high-quality grain and maximum biomass from limited resources. However, they often are inefficient in terms of maximizing grain production. Landraces typically have harvest indexes (the proportion of grain biomass to total plant biomass) of about 20 percent while HYVs can reach 40 percent or more (4). Crop breeding can substantially increase grain yields by improving the plant's ability to partition the biomass it produces into grain. However, minimal research has been conducted on most of these crops to date, so much work remains and progress will be gradual. Since crops are grown for fodder and other purposes besides human consumption, these multiple objectives should be reflected in breeding priorities.

Rewards from breeding will be increased if they can be used as catalysts to bring about additional agricultural changes. Yield increases can begin a cycle of economic growth. For example, a crop yield increase from 600 to 800 kg/ha represents a 33-percent gain in productivity. But the farmer's profit may be doubled, tripled, or even increased tenfold, depending on the initial break-even point. Thus, the farmer has more income to purchase, among other items, additional inputs that will further increase yields, reduce drudgery, etc. When local entrepreneurs are stimulated to produce these inputs, such as small-scale machines, the development process is further enhanced.

Crop Brooding Cautions

Crop breeding often has resulted in replacing traditional landrace mixtures with pure lines of improved varieties. This practice can increase a crop's vulnerability to new epidemics and environmental stresses. First, since appropriate breeding emphasizes resistance to pests, improved varieties should be less susceptible to pest damage than original landraces. However, the ongoing co-evolution of pests and their host plants requires continued genetic input from traditional varieties to maintain the gains from breeding (39). A recent proposal calls for incorporating landraces and wild relatives of crops into development assistance efforts. Traditional cropping systems can be "modernized" while still serving an important role as crop germplasm repositories (2]. Second, the risk of a disease or pest epidemic increases if the mixture of varieties planted in an area is replaced by any one variety, regardless of whether it is an "improved" one or not. Therefore, many varieties should be used rather than planting extensive areas with one genetic type.

Another caution to consider when introducing new varieties is that they should not adversely affect the biological equilibrium between the crop and pests and diseases. The first sorghum hybrids used in India carried no resistance to Striga, a major parasitic weed. Seeds from the weed are now much more abundant than they were traditionally, and they persist in the soil for 10 years. Striga generally is a more serious problem in Africa than Asia. Thus, the potential for a similar incident to occur through the careless release of a crop variety with insufficient resistance is greater in Africa (4).

Scientists conducting breeding efforts should try to anticipate the social effects of their work. The Green Revolution in Asia has been criticized for increasing existing social inequality. An evaluation of the Consultative Group on international Agricultural Research (CGIAR) system, however, disagreed, arguing that reductions in the price of grains favor the poor more than the rich who spend a smaller portion of their income on food. They go on to caution, however, that "technological advance, while vital for the development of agriculture and the economy, is a poor instrument for redistributing wealth" (27). Another social issue involves the need to understand demands on labor, including household division of labor. A critical issue in regard to the expansion of root crops, for instance, is the potential increased demands *on* women's labor. Since women have responsibility for producing and processing most of these crops, any expansion should also be accompanied by improved production techniques, improvements in extension and local processing facilities, and increased access to credit (52). The role of biotechnology in plant breeding may raise similar equity issues (box 9-2),

Problems and Approaches

Many non-technological factors that impinge on food production, such as the need for African governments to improve incentives for farmers to grow food, also apply to the issue of crop breeding. Markets for inputs and outputs need to be developed and stabilized wherever possible. Concerns are also expressed regarding the distortion of local tastes and demands that result when donors supply food aid in the form of crops that cannot be grown locally. OTA has identified several problems more specific to crop breeding,

1. Decreasing the Gaps Between On-station and On-farm Results

One of the most striking features of African agriculture is the small impact that improved varieties have had, despite the dramatic results achieved at experiment stations. On-station yields commonly are on the order of 40 to 60 percent greater than on-farm yields (31). Several activities could help reduce the gap between on-station and on-farm results:

- *Collect baseline data on present crop production levels and constraints:* Farming systems research (FSR) can ensure that breeding objectives are developed with farmer input, based on knowledge of the farming system in which the improved variety will be used, and that the varieties are viable when used under the conditions and constraints facing the farmer. FSR teams should evaluate improvements such as improved processing ability, not just yield increases, resulting from use of improved seed.
- *Include a mix of natural and social scientists on the research team:* It is particularly important that women be well-represented among researchers and extensionists. African women have primary responsibility for consumption decisions and, therefore, strongly influence the adoption of improved varieties.
- *Identify improved varieties that have performed well under similar agroecological and socioeconomic conditions:* These varieties from other continents or simply from other parts of Africa need to be extensively screened under local conditions.
- *Increase on-farm research and trials:* A proper balance is needed between creating appropriate genetic variability on the

Box 9-2.—Biotechnology's Impact on African Agriculture

Biotechnology includes a variety of methods for introducing and reproducing new genetic variation in organisms as well as a number of industrial applications of biological processes. Specific technologies related to plant breeding include tissue culture and other techniques for propagating plants; fusion of plant cells (protoplasts) either within or between species; and precise recombination of DNA, the genetic material (53). These techniques could enable plant breeders to work faster, to adapt plants more precisely to specific situations, and to introduce new traits into crops either from other plants or from micro-organisms. In some cases, plant cell cultures could replace field-grown crops.

So far, certain types of biotechnology have moved rapidly into commercialization and are used in developing as well as developed countries. For example, some Kenyan farmers grow potatoes from materials provided by the National Plant Quarantine Station in Nairobi. These materials originated in tissue cultures sent from the International Potato Institute in Peru. Other, more complex biotechnologies have been slower to develop than expected. Significant impacts on plant agriculture are expected first in developed countries in 5 to 20 years (13,54).

The application of biotechnology to plant breeding in Africa continues to be small. Many methods rely on highly trained technicians and expensive laboratory equipment that is currently beyond the capacity of most African countries to purchase and maintain. Many plant breeders argue that African nations should draw on others' research results—especially those of the International Centers and the developed countries private sectors—rather than develop their own facilities. Enthusiastic support, including that of several African countries, for the new International Center for Genetic Engineering and Biotechnology suggests that developing countries prefer to develop their own capacity for biotechnology to a certain extent (37).

Plant breeding and other changes in African agriculture due to biotechnology are likely to be important in the long-term (13), Significant issues related to biotechnology's availability and use will have to be resolved, though. For example: Unlike many plant breeding improvements in the past, biotechnology is concentrated in the private, not public, sector of developed countries, How can interested countries ensure access to the benefits of this research, What long-term relationships with U.S. firms and/or universities might be possible? How might African governments and farmers derive greater benefits and incentives to maintain the valuable germplasm resources contained in the diverse genetic base of their agricultural and wild species? How can biotechnology's benefits be provided to resource-poor farmers and herders when they are not major consumers of its products, nor are they likely to have the skills, money, and market experience to take full advantage of new methods? Perhaps most importantly, how can African countries prepare for the possibility that major export crops such as pyrethrin and cocoa, and the livelihoods of the farmers who produce them, may be displaced by genetically engineered products in developed countries?

experiment station and adaptive research under on-farm conditions. Experiment stations allow for research under more controlled conditions, such as artificially high-pest pressures. On-farm trials increase the probability that new varieties will be useful under farmers' conditions and increase rates of adoption. Farmers' fields can also be used to preserve diverse genetic material.

2. Choosing Appropriate Breeding Priorities

The research agenda chosen by crop breeders can enhance this discipline's contribution to African food security. The new emphases on ensuring that improved varieties meet the objectives of resource-poor farmers and fit into their farming systems are particularly critical for Africa. A consensus is emerging on the ob-

Photo credit: Donald Plucknett/Consultative Group on International Agricultural Research

On-farm research is crucial to increasing the impact of improved varieties. In Rwanda, this farmer and scientist work together to test different crop combinations and various soil and water management schemes for growing cassava, plaintain, and maize.

jectives of genetic improvement programs that will most benefit resource-poor farmers and herders:

- Varieties that are higher yielding under farmer conditions: Researchers are paying more attention to developing varieties that produce a reliable yield under the variable, often adverse conditions of the farmer —and less emphasis on their ability to yield well under the ideal conditions created at the experimental station.
- Yield stability: An improved variety must be able to produce in bad years. This trait is a prerequisite to breeding efforts directed at maximizing yields under a range of environmental conditions.
- Pest and disease resistance: Protecting crops from pests and diseases can be one of the most effective means of increasing and stabilizing production.
- Tolerance for environmental stress: Breeding can improve crop tolerance for adverse environmental conditions, rather than requiring that the environment be modified.
- Improved quality, storage, and ease of processing: Criteria for improving quality include increased protein content and fewer toxic and anti-nutritional factors. Adoption of varieties will be enhanced by efforts to ensure that the harvest can be stored and processed to fit local consumption preferences.
- **Adaptation to diverse agricultural systems, reflecting the multiple uses of the products:** Improved varieties will be used more by resource-poor farmers if the improvements address their needs and fit their practices. For example, while the grain from cereals is used for human nutrition, the stalks *are* a valuable source of fodder, cooking fuel, and building material.

Even when an improved variety is shown to do well under farmers' conditions, a complex of factors influence adoption rates. For example, a newly developed sorghum hybrid (Hageen Durra I), released in Sudan, has generated excitement because it is capable of greatly increasing yields under experimental conditions. Although the hybrid yields less under resource-poor farmers' conditions, it still has been an important factor in raising production in Sudan. According to recent reports, however, it is suffering a serious setback. Now that food is more plentiful in some regions, farmers are returning to the traditional varieties because they are preferred for preparing a favored food, Kisra (30). Another factor in the shift is the inability of farmers to sell surplus sorghum at a price that justifies buying the more expensive hybrid (11). Even with improved varieties that the farmer does not have to buy each year, adoption rates are still low. Probably no more than 10 percent of the land in Africa devoted to cereal production is planted with improved varieties (49).

3. Matching Crop Research Funding With Importance for Food Security

Along with the shift in breeding priorities, there could be a redistribution of research funding so that attention to various crops would more closely reflect their respective contribution to the food security of the African people. The level of research that has been directed toward many African crops, particularly food crops, is low.

Table 9-2 presents rough estimates of research expenditures by commodity, expressed as a percentage of the value of production to the commodity. The data indicate that while certain export crops, such as coffee, cocoa, and sugar, have received substantial attention, food crops, particularly cassava and sweet potatoes, have been largely ignored, not only in Africa, but throughout the developing world. It is also notable that livestock have received considerably more attention in Africa, based on their relative economic value, than food crops (42).

Crop breeding research to improve food security should also direct specific attention to those crops most important to the resource-poor farmer, largely neglected to date. Only about 15 African scientists are concerned primarily with millet breeding on some 15 million hectares in about 12 African countries. About 100 breeders work on millet for roughly the same area in India. An acute need exists for all categories of scientists in Africa but it is not unrealistic to hope that 25 additional millet breeders could be trained by the year 2000 (4). In addition, the food legumes and the root crops, tubers, and plantains have been especially neglected. A key factor causing this neglect is the predominant subsistence use of these crops.

In the short term, operating funds could be increased for existing scientists. A supplement of $20,000 per year would enable a scientist to pay most operating costs (fuel and cultivation, consumable field and lab supplies), buy basic equipment, and provide and run simple seed storage operations (4).

4. Improving Seed Multiplication and distribution

In order to achieve benefits of improved varietal development on a wide scale, African countries need to develop or gain access to viable seed industries. Currently, few African countries have adequate seed industries—public or private—that can handle, process, store, or market seeds. Moreover, few have mechanisms to test improved varieties in farmers' fields, or have adequate seed laws to encourage indigenous seed industries or promote private external investments (38,50).

Low seed multiplication capability is a major obstacle to wider use of improved varieties, especially maize, but also for millet, sorghum, and rice. Also, low multiplication rates or genetic purity problems exist in crops such as groundnut, cowpea, and cassava (3). As a result, farmers are unable to obtain improved varieties despite crop breeders' successes. Local seed production and distribution is preferred

Table 9-2.—Research Expenditure as Percentage of Product Value, by Commodity, for Selected Countries in Different Regions of the World (average of 1972-79 period)[a]

Commodity	Region: Africa[b]	Asia	Latin America	All countries	International centers
Starchy Staples:					
Wheat[d]	1.30	0.32	1.04	0.51	0.02
Rice	1.05	0.21	0.41	0.25	0.02
Maize[e]	0.44	0.21	0.18	0.23	0.03
Cassava	0.09	0.06	0.19	0.11	0.02
Potatoes	0.21	0.19	0.43	0.29	0.08
Sweet potatoes	0.06	0.08	0.19	0.07	0.00
Field beans	1.65	0.08	0.60	0.32	0.04
Other Food Crops:					
Vegetables	1.56	0.41	1.13	0.73	0.00
Soybeans	23.59	2.33	0.68	1.06	0.00
Citrus	0.88	0.51	0.57	0.52	0.00
Export Crops:					
Cotton	0.23	0.17	0.23	0.21	0.00
Sugar	1.06	0.13	0.48	0.27	0.00
Cocoa	2.75	14.17	1.57	1.69	0.00
Bananas	0.27	0.20	0.64	0.27	0.00
Coffee	3.12	1.25	0.92	1.18	0.00
Groundnuts	0.57	0.12	0.60	0.25	0.005
Coconuts	0.07	0.03	0.10	0.04	0.00
Livestock:					
Beef	1.82	0.65	0.67	1.36	0.02
Pork	2.56	0.39	0.60	1.25	0.02
Poultry	1.99	0.32	1.12	1.64	0.00
Other livestock	1.81	0.89	0.42	0.71	0.00

NOTES":
aData on research expenditures by commodity have to be estimated indirectly and are consequently very rough. Data may vary considerably according to different sources.
bIncludes Egypt,Ghana, Kenya, Nigeria, Sudan, Tanzania, Tunisia, and Uganda.
cTwenty-six developing countries *accounting* for 90 percent of developing country agricultural research expenditures (excluding China)
dMost of the wheat research in Africa wascarfied out in North Africa.
eIncludes millet and sorghum research for Africa.

SOURCE: MA. Judd, J.K Boyce, and R.E. Evenson, "Investing in Agricultural Supply:' Economic Growth Center Discussion Paper No 442 (New Haven, CT: Yale University, 1983. As calculated by John M. Staatz, "The Potential of Low-Resource Agriculture in African Development:' contractor report prepared for the Office of Technology Assessment (Springfield, VA: National Technical Information Service, December 1987)

because of the need for local adaptation, but this may not be possible in many countries. Greater private sector efforts could be encouraged in this are abut an obstacle is that few African nations have adequate seed laws to protect companies' investments (38).

The potential for promoting private seed companies is very uneven in Africa. For poorer countries where markets and infrastructure are weak, private investment is unlikely. In such cases reliance on public efforts and access to germplasm from international centers is most important. A few examples exist where countries have been successful in developing indigenous seed multiplication industries or have capitalized on the use of imported high-yielding varieties. In Sudan, a dozen local farmers/ businessmen/entrepreneurs independently attempted to produce Hageen Durra I in 1985 and 1986, but it remains to be seen whether the effort is successful (3).

Some concerns have been expressed over undesirable consequences of seed laws that grant varietal patent protection needed to encourage private investments in developing countries. Cited adverse effects include negative impacts on research activities at international centers, establishing monopoly powers, and reducing germplasm diversity. There is disagreement over the existence or extent of such negative effects, but research shows that support for public plant breeding efforts (e.g., national and international research centers) help to counter them (55).

ANIMAL BREEDING

Although the donkey is the only major livestock species that originated in Africa, a diversity of animal breeds are now present there. Centuries of exposure to the wide range of environments and diverse management systems on the continent have allowed livestock to evolve and be actively selected to meet a range of needs. Some 50 varieties of cattle and similar numbers of goats and sheep have been identified (60). African livestock have been bred specifically to be able to cope with environmental stress and serve multiple uses. Not surprisingly, Africa's livestock tend to be late maturing, slow growing, and modest milk producers (6).

Although African livestock breeds generally are less productive than temperate breeds, they typically outperform them under the harsh environmental conditions and low-input management systems that exist in much of Africa. Therefore, little potential for genetic improvement to increase milk or meat production exists without reducing nutritional, disease, and climatic stress (6). Genetic improvement and use of exotic breeds will become more viable components of intensified systems as animal health, nutrition, and management are improved. Considerable potential exists to improve milk and meat production of ruminant breeds in certain favorable areas, specifically in highland regions. In lowland regions, environmental factors have led to management systems that typically provide little supplemental feed or health care, so the potential for production improvements is modest. Some potential exists, however, for genetic improvement in disease resistance.

The presence of tse-tse fly, which carries the disease trypanosomiasis, severely restricts cattle raising in about 40 percent of Africa. However, 5 percent of Africa's cattle, sheep, and goats display genetic resistance to the disease, so there is some opportunity for livestock breeding, evaluation, and selection programs to enhance this characteristic (see ch. 11).

Most livestock breeding programs in Africa have focused on cattle. Recently, small ruminants, and to a lesser extent camels, are being recognized as components of improved low-resource management systems. Breed improvement programs have stressed cross-breeding and introducing exotic breeds because these approaches provide visible and rapid gains in upgrading local stocks (23). However, few of these efforts have proven successful.

Resource-poor farmers and herders generally have not benefited from this emphasis on exotic cattle breeds. For poor rural people, exotic cattle are usually impossible or unattractive investments: they come in large valuable units which are not divisible while alive and which do not store well when dead. Only households already well buffered against contingencies can risk capital on exotic cattle. In contrast, the animals usually owned by poor rural people are cheaper and smaller. They may be native cattle, somewhat resistant to local diseases, or other species of animals (8).

While crossbreeding with exotic breeds and development of composite breeds (where environmental conditions allow) can enhance performance, recent research shows indigenous livestock to be more efficient producers than previously thought, thus warranting further investigation (60). Concern exists, however, that the lack of national breeding policies and the prevalence of indiscriminate crossbreeding programs are currently threatening a number of these potentially useful, indigenous livestock breeds with extinction (1,23).

The Potential of Specific African Animais

Cattle

African breeds of cattle fall into three main groups–the humped Zebu in the north, the humpless or taurine breeds that predominate in the tsetse fly-infested humid and sub-humid zones, and the small cervico-thoracic-humped Sanga common in the southern and eastern Savannah regions (6). Compared to temperate breeds, the potential to increase weight or milk production through genetic manipulation is generally low in these breeds (12). Because of these limitations, efforts to meet increased demands for livestock production, particularly cattle, have focused on crossbreeding and introducing exotic breeds. These breeds also fall under three basic groupings—Zebus (e.g., Sahiwal and Brahman types) from Asia and America, European beef and dairy breeds, and exotic Zebu/European hybrids such as the Bonsmara and Santa Gertrudis (6,44).

Despite considerable research on breed improvement in virtually every country in Africa, during colonial and post-independence periods, only some 3 percent of Africa's cattle herd has been affected (60). Most of this small improvement has occurred on cattle ranches and small dairy farms in a few select countries (e.g., Kenya and Malawi) (50). Surprisingly, little is known about the comparative performance of the various breeds (6). A review of some 500 papers on livestock research published between 1949 and 1978 show that only one-fifth have any comparative data and only one-quarter had data that enabled direct quantitative comparison (i.e., based on some common productivity index) (45).

Notwithstanding this poor track record and paucity of data, a few success stories exist. The case of development of dairy farming in Kenya is perhaps the most notable (21). In certain highland regions in Kenya, the use of cows crossbred between local and European dairy breeds has brought sixfold increases in milk yields. The number of these crossbred cows has increased significantly, averaging 14 percent per year between 1960 and 1975. Kenya Cooperative Creameries has emerged as a successful dairy enterprise supplied by a network of some 300 smallholder cooperatives. The success of this enterprise is attributed to: favorable climate, good infrastructure and markets, and support from government and extension services. Further increases may be possible in other highland regions with similar favorable conditions. For example, preliminary efforts to intensify milk production in the Ethiopian highlands seem promising (33).

Less dramatic, though more widespread, benefits may result from cross-breeding with breeds more suited to tropical conditions. For example, Sahiwal cattle from Pakistan were first introduced into Kenya almost 50 years ago and have since become a significant breed in some semi-arid regions (l). For much of Africa, however, the potential value of introduced breeds is small. As one assessment of prospects for breed improvement and conservation in the Sudan reported (36):

> [A]ny genetic improvement programme, involving crossbreeding or importation of purebred European cattle to the country for replacement of indigenous cattle, is not only impracticable but also undesirable. The use of exotic stock is at best a restricted activity in certain farms that can afford provision of improved feeding and management conditions not at present available in small farms and nomadic/trans-humant herds.

A need to focus increased attention on indigenous breeds is evident. However, many governments continue to emphasize crossbreeding and introduction programs despite a poor record of genetic improvement to date, and despite a basic lack of knowledge about breeds appropriate to the region (60). It is becoming increasingly clear, however, that priority inbreeding activities should be shifted to emphasize local stocks, particularly gathering and evaluating field data to establish their merits, limitations, and potential for improvement.

Photo credit: Donald Ptucknett/Consultative Group on International Agricultural Research

Gambian N'dama cattle are typical of several indigenous African breeds—they possess valuable genetic traits (in this case, tolerance to trypanosomiasis, a widespread disease).

A related priority for African livestock development is to take action to avoid extinction of various African breeds. Some efforts already have been launched, but potentially valuable genotypes continue to be threatened for a variety of reasons (table 9-3). There is a need for additional national and international breed conservation efforts (23,55).

Small Ruminants and Canals

Just as the so-called "poor peoples crops" (e.g., roots and tubers) have been largely overlooked in crop research, small ruminants (e.g., sheep and goats) and camels have suffered similar neglect despite their important role in providing animal protein in African diets. Interest in these animals is increasing, however. Within the last few years, for example, the International Livestock Center for Africa has organized a Small Ruminant and Camel Group to identify, disseminate, and promote research. Also promising is the work of the Small Ruminant Collaborative Research Support Program (SR-CRSP) in Kenya, particularly its emphasis on training African scientists in small livestock research.

Research from the Small Ruminant and Camel Group suggests that the reproductive performance of small ruminants within traditional production systems can be improved (26). Increased attention should be directed toward reemphasizing breeding controls that limit lambing or kidding to once a year because evidence exists that non-seasonal breeding among indigenous breeds can provide higher reproductive output. To optimize annual reproductive rates, livestock breeders may want to manipulate intervals between birthings, average age of breeding females, as well as litter size (26). Improved reproductive performance has also been obtained from camels as a result of improved management and nutrition—reducing intervals between births from 26 to 18 months. These improvements reinforce the notion that better animal husbandry holds more immediate potential than genetic improvements.

Disease aggravated by poor nutrition is the major constraint on small ruminant production

Table 9-3.—Endangered African Cattle Breeds

Breed	Location	Main use	Reasons for decline in number	Traits that justify conservation
Maturu	Nigeria	Meat, draft	Crossbreeding; lack of interest by farmers as tractors become available; Nigerian civil war	Trypanotolerant; ' hardy; good draft animal; low mortality; short calving interval
Lagune	Benin, Ivory Coast	Meat	Crossbreeding; lack of interest by farmers because of small mature size (125 kg) and low milk yields	Trypanotolerant; adapted to humid environment
Mpwapwa	Tanzania	Milk, meat	Lack of sustained effort to develop and maintain breed	Adapted to semi-arid plateau of central Tanzania
Baria	Madagascar	Milk, meat	Crossbreeding	Adapted to local environment; humpless
Creole	Mauritius	Milk, meat, draft	Crossbreeding	Adapted to local environment
Kuri	Chad; Nigeria	Milk, meat	Numbers greatly reduced by rinderpest and drought; political instability	High milk production potential; able to swim long distance; tolerant of heat and humidity
Kenana	Sudan	Milk,	Crossbreeding; loss of major habitat to development scheme	Good dairy animal; adapted to hot, dry environment
Butana	Sudan	Milk	Crossbreeding	Good dairy animal; adapted to hot, semi-arid environment
N'Dama	Gambia, Senegal, Guinea	Meat	Crossbreeding	Trypanotolerant; efficient meat producer under poor conditions

'Ability to survive Trypanosome Infection (spread by tse-tse fly) that causes African sleeping sickness in cattle.

SOURCES K O Adeniji, "Recommendations for Specific Breeds and Species for Conservation by Management and Preferred Techniques," U N Food and Agriculture Organization, *Animal Genetic Resource Conservation by Management, Data Banks, and Training,* FAO Animal Production and Health Paper No 41 (Rome FAO, 1984); pp 89-98 and R McDowell, Visiting Professor, Department of Animal Science, North Carolina State University, Raleigh, NC, personal communication, 1987

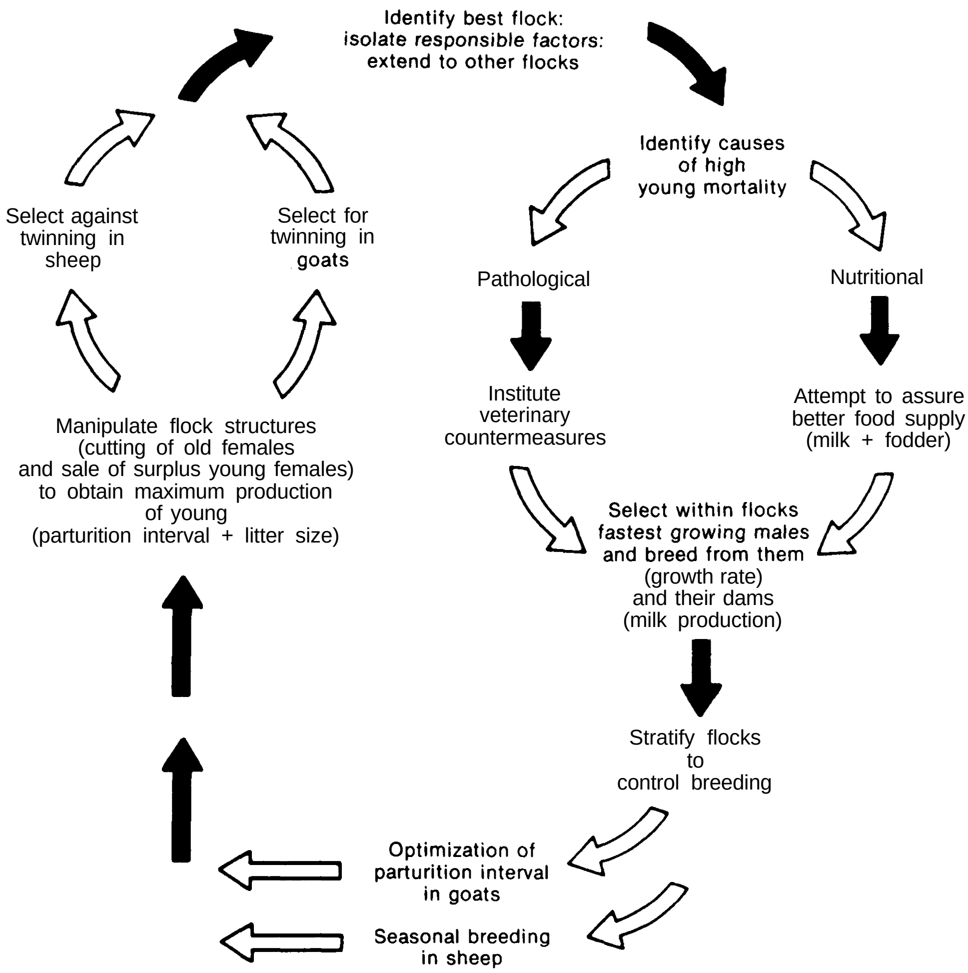
(57). Breed improvement and selection is thus important primarily as a component of improved management systems. An integrated research approach to developing improved production systems would have to consider a variety of needs. For instance, in a project to enhance goat milk and meat production, crossbreeding and upgrading indigenous breeds were done in conjunction with improving nutrition and management (58). Preliminary evaluations suggest that low-cost improvements could double production beyond that of using large ruminants (24). Although most research is focused on areas where the environment is favorable, improvements are also possible in less accommodating environments (46).

Research on small ruminants in Africa has shown consistently large variation in output among different flocks of sheep and goats within various regions—as much as fivefold differences between the best and worst flocks (57). These differences are principally a function of individual management. This suggests that significant increases in productivity and improvements to human welfare can likely be achieved by low-technology, low-cost packages based on improving existing management practices and existing biological potential within traditional systems already found in Africa (57]. Figure 9-1 outlines, in general terms, a set of "improvement pathways" based on the best features of an existing pastoral system in Kenya.

Poultry and Swine

Poultry production is ubiquitous in Africa, but the intensity of production varies greatly. By far the most prevalent is the traditional scavenging system using local breeds and little supplementary feed, water, or veterinary care (50). Since the threat of a disease that can quickly wipe out entire flocks is ever present, farmers are discouraged from maintaining large numbers of fowl or investing much in supplementary care. However, research on progressive intensification of traditional, low-input management systems suggests that major increases in production would be possible given access to adequate health services (table 9-4). Use of improved or introduced breeds may be important only in the latter phases of inten-

Figure 9-1.—Potential Improvement Pathways for Traditionally Managed Small Ruminant Flocks on Maasai Group Ranches



NOTE: Open arrows indicate alternative or secondary pathways

SOURCE: R. Trevor Wilson, "Goats and Sheep in the Traditional Livestock Production Systems in Semi-Arid Northern Africa: Their Importance, Productivity and Constraints on Production," *Livestock Development in SubSaharan Africa: Constraints, Prospects, Policy,* J. Simpson and P. Evaneiou (eds.) (Boulder: CO, Westview Press, 1984).

sification. Research on marketing strategies, in support of such increases in production potential, would also be necessary.

Swine production is a relatively minor component of livestock production in Africa, concentrated primarily in West African coastal areas. Breeds are nondescript Iberian types introduced by the Spanish and Portuguese, well adapted to scavenging production systems and resistant to many diseases (50). Some improved breeds (e.g., Large White) have been introduced subsequently, and productivity increases have resulted from improved management and feeding (e.g., with manioc, bananas, and oilseed cakes). African swine tend to carry a number of diseases and parasites transmissible to humans and, thus, intensive management in close proximity to humans may present health problems.

It is likely that most gains in pig production in Africa, derived from use of exotic breeds, will occur as a result of large-scale Western production technologies located near urban centers where demand exists. Swine production, as well as poultry production, represent perhaps the only examples where direct introduction of large-scale livestock production technology has proven widely successful.

Table 9-4.—Poultry Productivity Under Different Management Systems

System	Characteristics	Eggs hen/yr	outputs 1 yr. old chicks/hen	Eggs for consumption
Traditional	Scavenging; no water, feed; inadequate night shelter.	20-30	2-3	0
Improved traditional Step 1	Regular water and grain; improve night shelter; care of hen/chicks in first week; Newcastle vaccination.	40-60	4-8	0
Improved traditional Step 2	Same as Step 1 plus further improvement in feeding, watering, and housing. Treatment for ecto- and endoparasites. Additional vaccination as indicated.	approx. 100	10-12	30-50
Improved traditional Step 3 (semi-intensive)	As Step 2 but with improved breeds; complete diet; hatching by local hens.	160-180	25-30	50-60

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

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