chapter 5

The West African Semiarid Tropics

Peter J. Matlon

The West African semiarid tropics (WASAT) are defined as those areas where precipitation exceeds potential evapotranspiration from two to seven months annually. This corresponds to mean annual rainfall limits of approximately 250 to 1,300 millimeters. The area encompasses all of Senegal, the Gambia, Burkina Faso, and Cape Verde; major southern portions of Mauritania, Mali, and Niger; and the northern portions of Ivory Coast, Ghana, Togo, Benin, and Nigeria. Except for Senegal, all are classified by the World Bank (1981b) as among the poorest third of the world's developing countries, with mean per capita incomes of $320 or less. These countries are experiencing rapid population growth and remain primarily rural.

Cereals occupy nearly 70 percent of total cultivated area in the WASAT, and absorb 50 to 80 percent of total farm-level resources. Millet and sorghum account for roughly four-fifths of cereals production, but yields are less than half those for cereals in Africa outside of the WASAT. During the 1970s, cereal output grew about 1 percent annually, due primarily to area expansion.

Compared to the whole of Africa, pressure on the land in the WASAT appears to be low, with only 3 percent of the total land area under cultivation in any given year. For continental Africa, this figure is 6 percent. Moreover, the average density of agricultural population in the Sahel is 156 inhabitants per square kilometer of cultivated land, compared to 183 for all of Africa (FAO 1982a).

The amount of land potentially available for cultivation, however, is considerably less than the above figures might suggest. Substantial portions are

The author wishes to thank Wilhem Stoop of the Royal Tropical Institute who reviewed and commented on drafts of this chapter.

unsuitable for agriculture due to desert conditions, large expanses of rock outcropping, and so forth. The distribution of the rural population is also not always positively associated with agricultural potential.[1] Moreover, due to microrelief, soil quality can vary widely within even small areas. Thus even in zones of only moderate population density (30 to 50 persons per square kilometer), the better soils often are already under cultivation, and the expansion of cropped area means declining production potential with existing technologies. Finally, soils in the WASAT tend to be unstable, with productivity rapidly declining under continuous cultivation. The traditional bush-fallow system can require a five to one or higher ratio of fallow to cultivated land to maintain soil quality.

Within the WASAT, east-west isohyets delimit a set of agroclimatic zones with distinct agricultural systems and development potential. Most generally, one distinguishes three zones: the Sahel, the Sudan, and Guinea. The first two form the primary focus of this chapter.

The Sahel includes all farmed areas of Cape Verde, Niger, and Mauritania, one-third to one-half of the cultivated areas of Senegal, Mali, Burkina Faso, and Chad, and smaller portions of northern Nigeria (Norman et al. 1981). This zone receives 250 to 750 millimeters of rainfall and has a rainy season of 60 to 120 days. The shortness of the growing season, low and variable rainfall (especially during planting and grain-filling periods), and low soil fertility are the principal constraints to agricultural production.

The Sudan zone includes the Gambia, the southern portions of Senegal, Mali, Burkina Faso, and Chad, most of northern Nigeria and northern Cameroon, and portions of northern Ivory Coast, Benin, Togo, and Ghana. Rainfall is less variable, ranging from 750 to 1,300 millimeters, and the growing season of up to 150 days occurs from May to October. The Sudan zone has a wider range of crops, higher yields, and a greater development potential than the Sahel.

CLIMATIC AND SOIL CONSTRAINTS

Several climatic characteristics other than low rainfall limit the region's agricultural potential. The WASAT has a significantly shorter crop-growing season than other semiarid-tropics (SAT) with similar rainfall. This limits the transfer of certain technologies, such as preplanting plowing for example, from semiarid India (Oram 1977). Although high temperatures and solar radiation during the rainy season are conducive to rapid plant growth, they also cause high evaporation, which reduces available soil water. Unlike the Indian SAT, evap-

1. This is often due to tribal or colonial history (for example, the Mossi Plateau in Burkina Faso) or to disease (for example, onchocerciasis in many of the major river valleys).

orative demands are highest in May and September, the planting and grain-filling periods, increasing the risk of early and late season water stress. Furthermore, rainfall intensities are two to four times greater than in temperate climates. The result is high risk of topsoil erosion and loss of up to 60 percent of rainfall through runoff.

Even in years of "normal" total rainfall, distribution tends to be erratic, with drought periods of two weeks or longer common, particularly in the Sahel. Variation in annual totals is also high. The annual coefficient of variation of rainfall is 20 to 30 percent in the Sudan and 30 to 50 percent in the Sahel. Rainfall data also reflect the tendency for abnormal years of rainfall to occur in more or less uninterrupted periods for as many as 15 years (Nicholson 1982). Consequently, systems of production, storage, and exchange cannot be based exclusively on expectations of an average climatic situation. Rather, the food system must be sufficiently flexible to reduce the welfare impact of a series of bad years, while permitting reasonable exploitation of resources during good years.

Charreau (1977) has defined two broad soil groups in the WASAT, which correspond roughly to the rainfall belts described above. Between the 200- and 500-millimeter isohyets, modal brown and reddish-brown soils (camborthids) predominate. Further south, between the 500- to 900-millimeter isohyets, the most common soils are red to grey, ferruginous, leached soils (ustalfs). High-potential alluvial soils and black clay soils (vertisols), which occupy large areas of the Asian SAT, are far less common in the WASAT and tend to occur only in the more southern belts in isolated patches. Soil texture varies from loamy sands in the northern Sahel to sandy loams in the southern Sudan areas. Except for the limited vertisol pockets, clay content is uniformly low, less than 20 percent, and the soils are structurally inert and have poor water-holding capacity. Compared to the red soils of the Indian SAT, the clay content of typical WASAT red soils is approximately one-half (Stoop et al. 1981). Soil depth is generally shallow, thus further limiting the soil's water storage, except in the extreme north, where eolian deposits result in deep sands merging into dune conditions.

Both soil groups have low to very low natural fertility. Due to low clay and organic matter content (generally less than 1 percent), cation exchange capacities tend to be less than five milliequivalents per 100 grams of soil. As a result, the soils are highly fragile. Although nitrogen and phosphorus are commonly the most limiting nutrients, other deficiencies (potassium, trace elements) and acidification are readily induced by intensified continuous cropping (Pichot et al. 1981).

In addition to low natural fertility, the major physical properties of WASAT soils that limit crop production potential include: (1) very low structural porosity and consequently high bulk density, which reduces root penetration and water circulation; (2) a tendency for compacting and hardening during the dry season, which results in high early season runoff and which severely restricts preseason and postseason cultivation; (3) generally poor infiltration, except on eolian sandy soils, due to rapid surface crusting of soils even after cultivation; (4) low values of available water compared to typical Asian SAT soils (Virmani et al. 1978); and (5) increasing susceptibility to erosion with continuous cultivation. Combined with the climatic conditions described above, these characteristics result in a general fragility, which can cause rapid deterioration of soil productivity under some forms of intensification.

Within the broad soil groups, microvariations importantly determine production potentials of particular fields. Farmers have adapted to these variations with highly flexible management practices. For example, millet is mainly grown on the shallow, gravelly soils generally located on the plateau and upland portions of the catena. These soils tend to be droughty, rapidly exhausted, and subject to high risk of erosion. Deeper soils (sandy or silt loams in the Sudanese zone) often occur in depressions and become more plentiful toward the mid-slope and lowlands. Less drought-tolerant crops, including sorghum, maize, and rice, are sown in these areas. One result of microvariability in soils is the highly fragmented patterns of traditional cropping systems and the often uneven adoption of components of improved technology.

MAJOR CROPS

Cereal cropping patterns in the WASAT gradually change from short-cycle, drought-tolerant varieties in the Sahel to longer-cycle, more drought-sensitive crops in the Sudan. The major crops and their areas of concentration are as follows:

Millet is grown throughout the WASAT, from the Sahel to the southern Guinea savanna, but is the dominant cereal between the isohyets of 250 to 650 millimeters. Sorghum production is generally concentrated in areas of 650–1 thousand millimeters, where it is the principal food grain. In traditional systems in the Sahel and the central Sudan, maize cultivation is limited to heavily fertilized soils adjacent to compounds and on the margin of swamps, where it rarely exceeds 3 percent of total cereal area. Only in the southern Sudan and in northern Guinea does maize replace sorghum as a major field crop. Rice is a minor crop throughout the WASAT, with cultivation limited to unimproved or moderately improved swampland. Cowpeas, the major grain legume in the WASAT, is usually grown as an intercrop at low density (1 thousand to 8 thousand plants per hectare) with millet or sorghum.

The regional importance of export crops is influenced more than food staples by institutional factors (credit, input, and marketing services) and by price factors, both of which vary widely between countries. Although groundnuts remains a major export crop in Senegal, diseases and unfavorable prices for groundnuts have substantially reduced planting since the early 1970s, especially in northern Nigeria. Cotton is a major cash crop in large areas of the Sudan and the northern Guinea savanna. Particularly within the francophone countries, cotton production under relatively high management conditions has been successfully promoted by national parastatals.

Farm units throughout the WASAT tend to diversify the crop mix to reduce aggregate production variability, to produce most of the foods required in local diets, to satisfy part of family cash needs, and to exploit soil microvariability (Norman 1974; Abalu 1976). The range of mixtures is greatest in the southern zones (Kabore et al. 1983). Despite the traditional importance of intercropping, agricultural research has only recently begun to explore improved intercropping systems.

FARM PRODUCTION UNITS

Most of the agricultural production in the WASAT is from small, family-based farms. The operators range from relatively small nuclear families to large, extended or compound families. Unlike in the Asian SAT, a landless class of workers has not yet emerged. The cultivated area per household generally averages between two and six hectares. The distribution of land among households tends to be highly equitable, with some exceptions in areas of high population density (Matlon 1981). Nevertheless, there is evidence that conventional forms of usufruct are increasingly yielding to rights of possession and transmission of ownership through inheritance, and that land control is becoming more concentrated.

Labor input per unit area, primarily from family sources, ranges from 350 to 1,200 hours per hectare, varying as a function of crop, population density, and length of cropping season. Periods of peak labor input generally correspond with planting and weeding, when timeliness can critically affect potential yields (Matlon and Newman 1978).

In traditional production systems, capital consists primarily of hand tools, seed, and small quantities of fertilizer. Nonlabor cash expenditures in manual systems without chemical inputs are low, generally less than $5 per hectare. In areas where hired labor is common, however, cash expenditures can be as high as $20 to $60 per hectare (Matlon 1977). In spite of efforts to extend animal traction since the early part of the century, probably less than 10 percent of farmers in the WASAT employ animals as a power source.

Nearly all farm households maintain fowl and small ruminants and, in some cases, cattle as easily liquidated forms of savings, insurance, and income. However, potential technical complementarities between livestock raising and cropping are rarely achieved. Under the traditional, extensive land-use systems, livestock forage away from the farm, with the result that most manure is lost. Systems of entrustment, whereby Fulani herdsmen manage the livestock of cultivators, are well adapted to this ecological setting (Delgado 1977). With mounting population pressure, however, two opposing forces point to the need for profound structural changes in current crop-livestock systems. With a shift to less frequent fallows, low organic matter levels are becoming a serious constraint to current production and to long-term soil stability. Substantially larger amounts of manure are needed to stabilize these systems than are currently being applied. And second, growing land pressure is concurrently reducing the area of wild forages and, in turn, livestock-carrying capacity.

It is generally held that WASAT farmers are allocatively efficient (which means insignificant production gains would result from a reallocation of available resources given present technology) and responsive to economic incentives. Although conventional wisdom states that farmers are averse to risk and generally conservative with respect to innovation, in fact little rigorous empirical research on farmers' risk attitudes and behavior has been done in the WASAT (Norman et al. 1981). Moreover, the wide-spread adoption of groundnuts and cotton and the active, "traditional" experimentation with new cereal varieties (ICRISAT 1983) demonstrate the openness of farmers to change when adequate incentives and means are available.

WASAT farming households typically pursue other income-earning activities, such as crafts, salaried labor, and crop and noncrop trading. In the highly monetized rural economies of northern Nigeria, for example, these activities can contribute up to one-third of total farm household income and more than one-half of net cash revenues (Matlon 1981). The highly variable returns to labor in nonagricultural employment are location specific and trade specific. In northern Nigeria, average returns in more than 20 nonagricultural occupations are roughly 50 percent greater than the farm wage rate, which is approximately equal to the marginal value product of farm labor. Returns to labor in the most capital-intensive occupations are generally two to three times the farm wage rate (Matlon 1977). Migration to urban areas and to coastal countries for off-season or multiyear employment is also important and poses an attractive alternative to farming to the younger generation.

Support services to small farmers are generally poorly developed throughout the WASAT. Understaffing, multiple responsibilities for agents, lack of transportation, inadequate supplies of inputs, and insufficient training characterize the national extension services of most WASAT countries. Ratios of farmers to extension agents are as high as 3 thousand to 1 (USDA 1981). Two important exceptions to these more general patterns are parastatals, which are responsible for extension services for cash crops, for input supply, and for marketing programs; and externally financed, integrated, agricultural development projects, as in northern Nigeria.

TRENDS AND IMPLICATIONS FOR TECHNICAL CHANGE

Fundamental structural changes are now occurring in WASAT farming systems. With population growth, cultivation is being systematically expanded to fields more distant from habitation and to marginal soils, which were formerly avoided due to lower fertility or greater drought proneness. The traditional bush-fallow method of maintaining soil quality is being abandoned, with a consequent decline in fertility, permanent elimination of vegetative cover, and increasing erosion. Alternative methods of maintaining the topsoil and the fertility of marginal soils under intensive cultivation are required. Similarly, local cereal varieties originally selected for cultivation on the most favorable soil types are increasingly less well adapted to the less fertile, more shallow, drought-prone soils now being brought under cultivation.

Increased economic opportunities both within and outside agriculture have resulted in a trend away from large family units and toward more individual decisionmaking. Simultaneous changes in land tenure systems are resulting in greater personal control over landholdings—but also fragmentation of holdings. While these changes increase incentives to produce for personal gain and to invest in land improvements, they also reduce the effectiveness of traditional, communal support mechanisms, which protected families against severe welfare loss in case of crop failure. The dissolution of large units also reduces the feasibility of new technologies, which require large investments or group management to achieve economies of scale—for example, watershed-based land management and, perhaps, animal traction.

Finally, farmers are increasingly weighing investments of capital and labor in agriculture against opportunity costs in the nonfarm sector. On one hand, the growing importance of nonagricultural employment offers viable alternatives to farming and reduces incentives to develop stable, intensive cultivation systems for the long term. On the other hand, more capital from nonfarm employment is becoming available for reinvestment in farming. The issue is whether currently available technologies present sufficiently profitable agricultural investment opportunities.

TECHNOLOGICAL OPTIONS

The major areas of possible technological change are irrigation, other forms of land and water management, mechanization, genetic improvement, and the use of chemical inputs. We consider these in turn.

Irrigation

Areas under irrigation in eight Sahelian countries have increased at an annual rate of 3 to 5 percent during the last two decades. Despite this growth, irrigated areas currently account for only 3 percent of total farmed areas. Moreover, due to the lack of complete water control and general absence of double cropping, yields in both modern and traditional perimeters are low and highly variable. Annual yields of rice, the main crop under irrigation, range between one and three tons per hectare, for example—substantially below the potential of up to eight tons achieved under double cropping in parts of Niger (CILSS 1980).

The technical potential to expand irrigation substantially surpasses current levels. A study by the Food and Agriculture Organization reports that the Sahel has approximately 14 million hectares of irrigable soils, or roughly 20 percent of total arable land (FAO 1975). However, because seasonal flow patterns in the Sahelian river systems are extremely variable, substantial investment in dam facilities would be required for more complete water control and more intensive double cropping. And because of the generally flat topography of the region, opportunities for large dam construction are rare and costly. Similarly, although groundwater reserves are estimated to be substantial, it is generally conceded that costs of exploiting them rule out their use on a major scale for crop production, given foreseeable input and output price relationships (CILSS 1980).

In what appears to be an overly optimistic assessment, which assumes full exploitation of surface water, CILSS (1980) projects the irrigated agricultural potential of the Sahel sites that could be developed within 25 years to be 2.3 million hectares, approximately 10 times existing levels. A USDA report (1981) projects a similar technical potential based primarily on large-scale projects.[2]

The economic potential of large-scale irrigation projects is less encouraging. First, per hectare investment costs are substantial, varying between $5 thousand and $20 thousand (CILSS 1980; World Bank 1981a). Second, yields are not sufficiently superior to rainfed agriculture, due to poor water control, absence of double cropping, inappropriate agronomic packages, and lack of complementary inputs. Third, poor management and high recurrent costs result in inadequate maintenance of equipment and structures. Fourth, little consideration has been given to farmers' incentives and to the problems of incorporating traditional farmers into intensive and externally directed irrigation systems. Fifth, external costs, including loss of grazing and farming land, fishing opportunities, and movements of displaced population, can be considerable.

In a review of the limited available literature on the economics of irrigation in the Sahel, Sparling (1981) concludes the small-perimeter, labor-intensive irrigation projects tend to be substantially more profitable, privately and socially, than large-scale projects. The potential area affected by such projects, however, is extremely small.

2. The USDA study identifies at least 11 projects in the Sahel that could increase total irrigated area to over 1.9 million hectares.

Land and Water Management[3]

The most common method of maintaining adequate soil moisture and achieving soil conservation in traditional systems has been to alternate cropping with long bush-fallow cycles. Due to increasing population pressure, however, these systems are yielding to shorter grass fallows and in some areas to continuous cultivation. Alternative methods available or under research in the WASAT are soil tillage, including various methods of soil preparation and ridging; mulching; contour bunding; and watershed-based management. The scale of these techniques ranges from plot and field to watershed. Given the fragmentation of field ownership, larger-scale approaches, while technically more comprehensive, raise important ownership and group management problems.

Construction of ridges that are subsequently tied (at planting, at first weeding, or at flowering) has significantly increased water infiltration and enhanced yields under research station conditions in East Africa (Ruthenberg 1980). Experimental results in West Africa also indicate considerable technical potential for tied ridging. Yield response is greatest under conditions of soil moisture stress and where soil fertility is not limiting. Average yield increments of 1 thousand kilograms per hectare for maize (Rodriguez 1982), 930 kilograms per hectare for sorghum, and 570 kilograms per hectare for millet have been observed on research stations in Burkina Faso, where medium to high doses of NPK fertilizer have been applied (ICRISAT 1982).

Despite this technical potential, tied ridging is not practiced by WASAT farmers. Major questions concerning this technique are labor costs, the potential response under low-fertility soils typical of farmers' conditions, and the yield gap between the research station and farmers' fields, even with fertilizer complements. Limited on-farm tests in Burkina Faso suggest that yields under farmers' conditions are 60 to 90 percent below station results at high-fertility and low-fertility levels, respectively (Rodriguez 1982; FSU 1982). Returns to incremental labor at these levels are noncompetitive with labor use in flatbed systems.

Mulching has also received considerable research attention. The potential advantages of applying crop residues or free-cut straw as a soil cover are to increase infiltration, reduce erosion, control weeds, improve structure, and reduce soil temperature. Experimental results of mulching trials have been contradictory, however, probably because of variation in soil types, topography, and seasonal rainfall patterns.[4]

In traditional farming systems, mulch is generally applied by WASAT farmers in limited quantities on small areas and in special circumstances, such

3. This section draws heavily on Charreau (1977).

4. Charreau and Nicou (1971) in a general review of research results, for example, found no clear superiority of yields under mulching, whereas Perrier observed yield increases of 200 percent for both local and improved sorghum varieties in central Burkina Faso (ICRISAT 1982).

as on termite mounds or particularly shallow portions of fields where water infiltration or retention is limited. A major constraint to expanded use is that increasing amounts of available straw are being fed to livestock or used for construction, for mat making, or for fuel. The rising demand for straw as fuel and forage, in particular, suggests limited possibilities for expanding mulching on a significant scale.

The traditional use of bunds to control erosion and improve water infiltration, while observed in some areas of the WASAT, is rare and is practiced on a relatively small scale. In zones of high population pressure, for example, farmers occasionally construct small rock dikes across water courses to reduce runoff velocity and prevent gully erosion. Similarly, low dirt dikes are sometimes built around small, heavily manured household plots to avoid loss of fertilizer. Although early large-scale projects in the WASAT that employed unstable dirt contour bunds as a principal intervention were not successful,[5] evaluations of recent large-scale dirt-based bunding projects in Burkina Faso suggest considerable potential. In addition to the long-term benefits of reduced topsoil loss, recent farmers' tests in Burkina Faso have measured highly significant 20 to 80 percent yield increases in the short term (ICRISAT 1983). Visible yield increments on these magnitudes are probably essential to motivate farmers to maintain the fragile dirt bunds.

More stable, rock-based, water-harvesting bund systems have also been developed and extended on a relatively small scale in the most densely populated and environmentally degraded portions of the Mossi Plateau in Burkina Faso (Wright 1983). Although the potential of this method for increasing yields on currently cultivated fields has not yet been determined, it has been successful in bringing highly eroded, abandoned fields back into production and is probably one of the most promising technologies now available.

Comprehensive development of entire elementary watersheds, using alternating broad beds and furrows to reduce soil erosion and to increase the efficient use of watershed precipitation, has been successfully tested by ICRISAT in the Indian SAT. Although no research has been undertaken to determine the potential for transferring this technology to West Africa, differences in the physical characteristics of the two areas suggest that the potential is considerably more limited in the WASAT and that direct transfer of existing methods probably is not possible (Charreau 1977). The area of elementary watersheds in India is generally between 5 and 15 hectares, while that in the WASAT tend to exceed 100 hectares. As a result, investment requirements not only would be substantially larger in Africa, but a larger number of households would be involved, entail-

5. The bunds constructed in the Yatenga region of Burkina Faso during 1960–62—perhaps the largest of these early projects—have generally been judged a complete failure. Project planners bypassed the farmers, who, observing no immediate yield increase, failed to maintain the bunds. As a result, potential longer-term benefits in soil quality improvement were lost as the bunds eroded.

ing important management and tenure problems. The general flatness of the WASAT terrain also means that water storage facilities would be less efficient and would cover substantially larger areas of what are often the best and most intensively cultivated soils. Finally, economic analyses of the Indian systems have shown them to be profitable only on deep vertisols, which are rare in the WASAT, but not on medium or shallow vertisols or on alfisols, which are the most common soils in the WASAT (Binswanger et al. 1980).

Mechanization

It is currently estimated that little more than 15 percent of cropped area in the WASAT is cultivated by animal traction. Nevertheless, efforts to introduce draft-animal technology to WASAT farmers, under way since the early 1900s, are increasing. Since 1970, more than 50 projects involving a draft animal have been funded in francophone West Africa, alone (Sargent et al. 1981). Large investments in tractorization have also been made in several WASAT countries, particularly during the 1950s and 1960s, but with little success.

In the face of these continuing investments, assessments of the technical and economic impacts of mechanization in the region show mixed results. In contrast to major yield and labor-saving effects observed on research stations (Charreau and Nicou 1971; Kline et al. 1969; ICRISAT 1978), the limited available farm-level studies show that yield effects are generally insignificant and that area effects range between only 10 and 40 percent in the Gambia (Mettrick 1978), southeastern Mali (Whitney 1981), and Burkina Faso (Barrett et al. 1982; McIntire 1981).

A recent review of more than 100 animal traction projects in francophone Africa reveals common institutional and technical constraints, which limit fuller attainment of the potential benefits and thus block more rapid adoption (Sargent et al. 1981). First, adoption of traction systems tends to be lowest in areas where cash cropping is minor. It is likely, however, that this is better explained by institutional rather than technical factors. In areas such as the Sine Saloum in Senegal (groundnuts) and in southern Mali and southwestern Burkina Faso (cotton), where mechanization is well advanced, vertically integrated marketing institutions for cash crops provide short-term credit (for such subsidized complementary inputs as fertilizer), medium-term credit (for equipment and animals, intensive extension service, and veterinary support), and assured markets. Where such support systems are lacking, traction adoption rates remain insignificant.

Second, the range of mechanized operations performed by farmers is generally less than that required to achieve full benefits from an integrated traction system. Land preparation equipment—scarifiers and shallow plows in the sandy soils of the northern belt and deeper plows for the heavier soils further south—are often the only cultivation equipment adopted. Fewer than 25 percent of Sahelian farmers with traction equipment weed mechanically. This is a major constraint to area expansion in zones where plowing has been mechanized. As a result of the limited range of operations performed, animals tend to be grossly underutilized unless transportation is also mechanized.[6]

Third, the short rainy season tends to create severe labor conflicts between plowing and timely planting. This helps explain the lack of an adequate rental market for plowing and first-weeding equipment in all but the most southern zones, where the cropping and preparatory rainfall periods are longer. With rental equipment unavailable, each farm unit must amortize fixed costs for animals and equipment over its own cultivated area. Similarly, farmers rarely plow at the end of the season due to conflict with harvesting activities and due to the rapid drying and hardening of the topsoil after the rains end. As a result, full incorporation of crop residues is not achieved.

Finally, several studies suggest that, due to an extended learning period both for farmers and their traction animals, at least 6 to 8 years are required to achieve full farm-level benefits (Barrett et al. 1982; Jaegar 1984). During this period, credit for purchase of equipment and animals must nevertheless be repaid. Consequently, net incremental benefits tend to be negative during the first several years, creating a serious cash-flow problem for recent adopters. In addition, the risk to farmers of animal loss from sickness or death and of production shortfalls from climatic variability add a powerful disincentive.

These results, placed within the context of the region's demographic and ecological trends discussed earlier, have important implications for future animal traction programs and research. It must be recognized that the extension of area alone through animal mechanization is not a viable long-run option and must give way to intensive systems. Because farmers adopt land-extensive systems in part as a means of risk reduction, new land-saving approaches using animal traction as a key element must provide not only short-term profitability but reduced production variability and long-run land conservation benefits as well.

Thus complementary biological components should be considered part of an animal traction package. Cereal varieties more responsive than local varieties to plowing and that permit later planting—thereby removing the timing conflict with plowing—would increase returns to traction operations while simultaneously reducing weather-related risks. Similarly, greater integration of crop and livestock activities would allow farmers to more effectively manage and recycle biomass production for the maintenance of soil structure and long-term fertility. Since increased cash crop production may be necessary to assure the financial viability of animal traction, agronomic research should also focus on development of cropping systems incorporating cash crops into cereal-based

6. Barrett et al. (1982), for example, observe that in eastern Burkina Faso 45 percent of farmers with traction equipment used their animals for less than 50 hours per year in field work.

systems. Finally, efficient support services are needed, including farmer and animal training, credit, input and output marketing, veterinary care, timely equipment repair, and credit programs.

Crop Improvement

Breeding and varietal selection programs aimed at improving productivity of food grains have existed in the WASAT for several decades. The greatest advances have occurred in upland rice and maize, where a number of varieties developed by Institut de Recherches Agronomiques Tropicales and International Institute of Tropical Agriculture have met with some success. However, both are relatively minor crops in the semi-arid areas. Far less success has been achieved for sorghum and millet. Despite frequently encouraging on-station results, yield gaps of 40 to 60 percent are consistently observed when improved materials are tried on farms. Also, new varieties are often found to have undesirable consumption or storage qualities. The result is that, within the entire region, only insignificant areas are now sown to improved sorghum and millet varieties.

Experience suggests that the relatively slow progress in sorghum and millet improvement is due to several factors: difficulty in adapting Asian varieties to African conditions; inappropriate crop improvement objectives in view of the region's soils, infrastructural development, and farm-level capital; overreliance on varieties and hybrids grown solely under research station conditions; and lack of feedback from the farm to the research station.

It has been observed that Indian millet is highly susceptible to African races of mildew, smut, and ergot. Moreover, physiological factors tend to accelerate the growth of the Indian varieties, causing them to be spindly and partially sterile (Scheuring 1980). Similarly, the high-yielding sorghum hybrid CSH-5, which had substantial success in India, experienced unacceptable problems of charcoal rot and lodging in station trials and farmers' tests in several West African countries.

With respect to objectives, priority in crop improvement programs in the WASAT has traditionally been given to identifying cultivars that yield well under high-input management. Although this general approach achieved substantial production gains for wheat and rice in South Asia during the 1960s and 1970s, critical differences in conditions have blocked similar progress in the WASAT. First, high-yielding varieties generally require increased plant density and the use of chemical fertilizers to obtain production potential. However, technical response rates to plant population and fertilizer are substantially lower and the risk is higher on soils with low water-holding capacity or when water control is absent, as is usually the case in the WASAT. Even in India, rates of adoption of high-yielding sorghum varieties and use of chemical fertilizer tend to be greatest in areas of more assured rainfall or greater irrigation density (Jha et al.

1981). Second, extension support and the infrastructure for supply of improved biochemical inputs is considerably less well developed in the WASAT than in most Asian countries. Third, since land pressure is substantially lower in the WASAT than in the Asian SAT, there is less immediate economic incentive to intensify land use through the use of complementary cash inputs.

In short, the risk to farmers of adopting varieties that require good soil moisture, high soil fertility, thorough soil preparation, and other aspects of good management in order to outyield local varieties, may be unacceptable. Such varieties are unlikely to be adopted on a wide scale in the near future, though some may be suited to intensive development projects or to limited microenvironments.

At issue is the priority given to management-dependent high yields, to the practical exclusion of other possible breeding goals. Moderate yield increases and substantially greater stability could be achieved through breeding for resistance to the most common pests and diseases, for greater resistance to drought, and for improved seedling vigor. Development of varieties with a wider range of agronomic characteristics, such as reduced crop cycle or modified plant structure, could also increase farmers' management options by opening new intercrop or relay cropping possibilities, by permitting late planting without yield loss, and by permitting cropping on the most drought-prone soils, where moisture limitations reduce the growing period. It must be recognized, however, that although such a strategy would achieve greater production stability it would likely have marginal impact in terms of aggregate production.

For the longer term, development of stable and more input-responsive varieties or hybrids is clearly necessary for major breakthroughs in cereal production. The shift will take time, however, and require major investments in both agronomic research and improved input supply infrastructure.

It must be emphasized that achieving success in crop improvement urgently requires greater interdisciplinary research at the farmers' level, involving specialists in physiology, plant protection, agronomy, food science, economics, and breeding. Greater a priori understanding is needed of the physical and social environment into which new varieties are being fit (Stoop et al. 1981; Oram 1977). Factors causing the yield gap between the research station and the farmers' fields need to be identified and on-station objectives and methods modified accordingly. Constraints and points of flexibility in current production systems need to be identified so that management practices can be adapted to new materials. Varietal selection should take into account the desirable characteristics for storage, processing, and consumption, as well as for production. This approach requires greater work with farmers at several stages of the breeding effort, rather than at the final stage of preextension screening as is conventionally done. A continuing, interactive relationship with farmers to define appropriate breeding objectives and to test concepts and materials should reduce the time necessary to develop well-adapted, improved materials.

Chemical Fertilizer

Despite an annual rate of growth of approximately 15 percent since the mid 1960s, use of chemical fertilizer in the WASAT remains below any other area in the developing world. Excluding Senegal, an average of less than one kilogram per hectare of NPK is applied to food crops in the Sahel,[7] and only about 10 percent of total cultivated area receives any chemical fertilizer. Major factors explaining low use rates are (1) costs of foreign exchange; (2) high transport costs to and within land-locked countries;[8] (3) low and variable response rates to local cereal varieties, particularly in areas with less than 700 millimeters of annual rainfall; (4) poorly developed extension and distribution systems; and (5) inadequate farm-level liquidity.

In several countries, parastatal agencies responsible for the production and marketing of cash crops have provided high-quality seed of more responsive cash-crop varieties and subsidized fertilizer on credit to small producers. As a result, rates of application are substantially higher on such crops as groundnuts and cotton than on cereals.[9] An additional result of the cash crop emphasis is that often the only fertilizer available for cereals are formulas developed for the cash crops. In Burkina Faso, for example, extension service recommendations for sorghum and millet are based on a complex fertilizer for cotton, despite evidence that this formula can actually reduce cereal yields after several years of continuous application (Pichot et al. 1981).[10] In fact, little research has been done to determine optimal formula and doses for different cereals by soil type and agroclimatic zone, or to determine the long-term soil effects of continuous fertilizer use.

Economic analyses of the response to available chemical fertilizers in the WASAT are limited in number and often biased by on-station conditions that positively interact with fertilizer (deep plowing, complete weed control, high

7. This compares with 1.4 for West Africa as a whole; 3.6 for East Africa; 29 for North Africa and the Middle East; 23 for Asia; and 33 for South America. These figures are for 1975 and are from IFDC (1977) and Oram (1981); also see chapter 2 in this volume.

8. Representative costs for Burkina Faso in 1982 are 39 CFA per kilometer ton by truck and 15 CFA by rail (Bonnal 1983).

9. It is estimated that in 1978 approximately 30 kilograms of fertilizer per hectare was applied to groundnuts in Senegal; and in 1981 nearly 100 kilograms per hectare was applied to cotton in Burkina Faso (Societe Africaine d'Edition 1983; SOFITEX 1982).

10. In trials conducted over 18 years in Burkina Faso, IRAT observed that sorghum yields steadily declined following seven years of chemical fertilizer application due to soil acidification, potassium deficiencies, and aluminum toxicity. Only large applications of animal manure with chemical fertilizer were found to counteract this effect (Pichot et al. 1981).

applications of organic matter, and so forth). Nevertheless, these studies demonstrate the technical response and maximum financial returns of recommended doses across a range of crops. Research during 1978–82 at two stations in Burkina Faso, for example, (IRAT 1983), indicate that the yield increment per kilogram of NPK nutrient was highest for maize (a ratio of 13.5 to 1), followed by sorghum (10.3), soybeans (8.6), cotton (4.3), millet (3.1), and groundnuts (2.3). At nominal prices and using only the direct costs of fertilizer, the ranking of crops according to financial returns was almost identical. Maize and sorghum were highest, at rates of return of 450 and 330 percent. Millet was lowest, with a return of only 37 percent, well below the FAO rule-of-thumb of 100 percent returns necessary for adoption under small-farm conditions. After eliminating the effect of a 49 percent fertilizer subsidy, however, only maize, sorghum, and soybeans showed positive returns under experiment station conditions (Bonnal 1983).

Responses are substantially lower for farmers' demonstrations, with financial returns one-half to two-thirds those on experiment stations. In five years of FAO farmers' demonstrations in Burkina Faso, for example, financial returns (with a greater than 40 percent subsidy in effect) to recommended fertilizer levels applied to sorghum varied between only 70 and 150 percent (FAO 1982a).

Response gaps are even wider when fertilized crops are managed entirely by farmers. Two-year farmers' tests of compound fertilizer (14:23:15) conducted in three agroclimatic zones of Burkina Faso, for example, concluded that, at the economic cost of fertilizer and when applied to local sorghum and millet varieties, returns justifying adoption occur only at low doses—50 percent of currently recommended rates—and only in the southern and central Sudan. Average negative returns were observed both years in the Sahel. Farmers' tests also showed the high risks of fertilizer use in arid conditions. During a year of below-average rainfall, incremental yields for local sorghum did not cover even the subsidized cost of fertilizer when applied at recommended rates on approximately 40 and 70 percent of farmers' fields in the southern and central Sudan, respectively. It is important to note, however, that fertilizer was both more profitable and less risky for the improved varieties included in these tests.

The production and distribution of rock phosphorus from large local deposits in several WASAT countries is also receiving increased attention. Although trials confirm residual yield effects of a basal dose of granulated rock phosphate, it is a generally less economical source of phosphorus than imported soluble phosphates (Bonnal 1983). Additional constraints at the farm level are the difficulties in applying and incorporating finely granulated phosphates and the multiyear delay in realizing the full yield benefits. Recent results with partially acidulated forms of rock phosphate show promise in overcoming some of these problems.

The above evidence suggests that increased use of chemical fertilizers now available to farmers in the WASAT does not offer an economically viable technology for sustained agricultural growth, especially in the drier areas. Low response of local varieties, high risk, and negative long-term impact on soil quality, combined with infrastructural and foreign exchange costs, underlie this conclusion.

Several key issues must be addressed by both researchers and policymakers if chemical fertilizer is to play a more important role. First, specific cereal-based fertilizer formulas need to be developed, which provide the nutrients required for different cereals under various soil and climatic conditions. Second, greater applied research is required at the farm level to better determine optimum dose levels, taking risk as well as profitability into consideration. Third, major investments are required in production and distribution of fertilizer and in the development of complementary inputs—particularly improved varieties and animal traction—if the potential of fertilizer is to be exploited. Fourth, greater basic and applied research must be directed to managing the long-term effects of fertilizer use on WASAT soils. Preliminary evidence indicates that combining livestock raising with crop growing, which recycles biomass through animal manure, may be essential to sustained chemical fertilizer use. Fifth, current price and subsidy policies must be reconsidered in view of the economics of available fertilizers. Fertilizer subsidies at present levels would appear to be justified only at implicit cereal prices well above domestic market and import price levels.

CONCLUSIONS—EVOLVING NEEDS AND RECOMMENDATIONS

Farming systems in the WASAT reflect a long process of adaptation to low and variable rainfall, generally poor and fragile soils, and readily available land. The extensive land-use systems, which have evolved under these conditions, are marked by low productivity per unit area and high yield variability. Soil quality has traditionally been maintained by long bush-fallow rotations, requiring at least a five to one ratio of fallow to cultivated land. In rapidly expanding areas of the WASAT, however, growing populations are upsetting this ecological balance by cultivating more marginal soils and by continuous cultivation. Increased cash needs are also inducing farmers in some areas to put greater resources into cash crop production, often employing technologies that accelerate a decline in soil quality. The immediate result is nearly stagnant growth in yields of food crops and a general fall in aggregate farm output per rural habitant. A more pervasive long-term effect in areas of greatest population density is the steady decline of the natural resource base.

Because these processes have developed unevenly in different locations, cropping intensities vary considerably within the WASAT. Production potentials as well as short- and medium-term technological needs also differ along the north-south axis and within climatic zones. In areas of low population density, there is still scope in the short run for labor-augmenting technologies to permit more efficient area expansion. In areas of highest land pressure, immediate priority must be given to technologies that will arrest declining land quality. Between these extremes, a mix of approaches may be appropriate, but each approach should be viewed as a stage in the evolution toward more stable long-run intensification.

For areas of lowest population pressure, marginally profitable animal traction systems may permit some expansion of cultivated area per worker. However, these require a substantial and continuing investment in support infrastructure and in the provision of complementary inputs. Moreover, a consistent approach toward the evolution to more intensive, ecologically sustainable, animal-based systems is generally lacking. In the southern and central Sudan, several technologies are now available that can achieve substantial yield increases in the short run under research station conditions. Yield increments 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.

As important in the long run is the absence of proven farmer-adapted systems to maintain soil quality under the high-input management necessary to achieve significant yield increases. Economic means to generate, recover, and recycle biomass at levels adequate to maintain the soil's organic matter are particularly lacking.

Reversing this situation will require not only continued investment in agricultural research but also important changes in conception and approach. First, the objectives of both research and development programs should reflect greater balance between immediate production gains and resource base conservation. This implies a broader set of research criteria and a multiyear time frame for the evaluation of new technologies. In the policy domain, this implies that subsidies may be justified for stable antierosion systems and for farm-level inputs with important long-term benefits. Profound structural changes are especially required to move toward more efficient, mixed farming systems. Because such systems imply radical changes in production objectives, in resource use patterns, and in interethnic group relations, both research and policy interventions addressing this issue must have a long-term evolutionary perspective.

Second, the complementarities among components of improved technologies, particularly those affecting soil moisture, fertility, and varietal change, argue for a package approach in technology development and extension. This is subject to two important qualifications. First, given limited farm-level investment capacity and the risks linked to poorly developed delivery systems, each component of such packages should be profitable when used in isolation and, as far as possible, should employ resources available at the farm level. Second, because of differences in the quantity and quality of resources among production units, packages should be developed that fit the needs of distinct farm types.

Third, research and development programs should be based on a finer definition of regional recommendation domains. A delimitation of zones that more accurately reflect rainfall, soils, population density, and major farming systems would permit greater specificity in research objectives and greater efficiency in applying results. It should be recognized, however, that, due to differences in potential among zones, application of standard profitability criteria to guide investment in production technologies will favor the relatively more humid southern zones, thus widening interregional income disparities.

Fourth, there is an urgent need for more emphasis on research off the research stations. The factors explaining yield shortfalls between the research station and farmers' fields need to be identified and fed back to modify on-station objectives and methods. Greater participation by farmers in the development and testing of technologies also is necessary to insure earlier, more efficient farm-level adaptation.