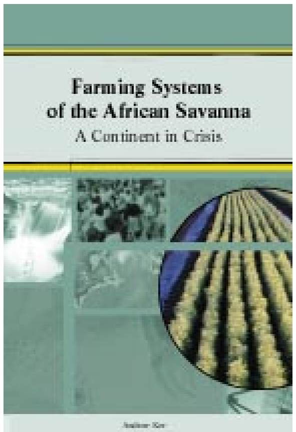
FARMING SYSTEMS OF THE AFRICAN SAVANNA
A Continent in Crisis



FARMING SYSTEMS OF THE AFRICAN SAVANNA
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Farmers in the parts of Africa where population growth is near, or has exceeded, the carrying capacity of the land at current technological levels face a serious crisis. This crisis is the result of the breakdown of traditional farming systems. The consequences are environmental deterioration on a massive scale, widespread poverty, malnutrition, and famine. In some countries, the crisis is contributing to political instability and civil war.

Through an examination of selected case studies, this book highlights some of the problems facing farmers in the African savanna and suggests some possible approaches toward solutions. It will prove useful to farmers, research and extension workers, policymakers, teachers, aid workers, and others who work with, or are concerned for, the future of the African farm and the livelihood of the African farmer.

THE AUTHOR

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Preface

The aim of this book is to highlight some of the problems facing farmers in the African savanna and to suggest some possible approaches toward solutions. Farmers in the parts of Africa where population growth is near, or has exceeded, the carrying capacity of the land at present technological levels face a serious crisis. This crisis is the result of the breakdown of traditional farming systems, which is causing environmental deterioration on a massive scale; widespread poverty, malnutrition, and famine; and, in some countries, is contributing to political instability and civil war.

I have not attempted a comprehensive review of savanna farming systems in this book. Instead, I have selected case studies of farming systems from throughout the savanna, and have tried to draw some general conclusions and principles from them. If this is accepted as a useful approach, I would suggest that African researchers might follow up as they think appropriate.

I have always considered it a privilege to serve the farmers of Africa, and I dedicate this book to them. I hope it will be useful to farmers, research and extension workers, policymakers, teachers, aid workers, and others who work with, or are concerned for, African farmers.

It is impossible to thank all those farmers, researchers, and others who have contributed in some measure to this book, but special thanks are due to the International Development Research Centre (IDRC), my employer for nearly 20 years, which enabled me to visit many of the countries of sub-Saharan Africa and supported research projects in several of them. Thanks are also due to Gil Croome for editing the book and to IDRC for publishing it, and to the staff of Reading University, UK, and especially Professor Hugh Bunting, who gave generously of his time during my sabbatical there.

Andrew Ker
Manotick, Ontario

Part I — Introduction

Chapter 1: Africa — The Changing Continent

Africa is perhaps the continent that is changing most rapidly at present. With the exception of Ethiopia and Liberia, all the other 43 countries of tropical Africa have achieved independence during the last 30 years. (As defined here, tropical Africa includes all the countries of sub-Saharan Africa and its associated islands except South Africa, which is mainly outside the tropics. See Appendix A.) These young states encompass an enormous diversity of environmental, economic, social, and political conditions. They contain some 800 different ethnic and linguistic groups making up a total population of over 500 million people.

The net rate of population increase in sub-Saharan Africa is now one of the highest the world has ever known, 3.2% per year (Harrison 1987, p. 20). Also, Africa is the only continent where population growth rates are still rising, as the rates started to decline in Asia and Latin America in the 1960s (Fig. 1).

If the present increase rate of 3.2% per year in sub-Saharan Africa continues, the population will double in 22 years, quadruple in 44 years, and increase eightfold in 66 years. This explosive increase in Africa's population is sure to continue well into the 21st century (Fig. 2). However, population densities in many African countries are still generally low, with fewer than 40 people/km^2, despite the highest increase rate in the world. In Asia, densities are much higher, ranging up to 600 people/km², with heavily populated areas exceeding 1000.

Food Production

It is well known that, since the late 1960s, food production in Africa has failed to keep up with the growth of population. In 1983–85 and again in 1991–92, drought and famine brought Africa to the world's attention. In 1984–85 in Ethiopia, almost eight million people were affected, and many died. After consuming all their scanty food reserves, farmers were forced to sell their sheep, goats, donkeys, cows, and then even their draft oxen and plows at rock-bottom prices to buy food, while the price of grain soared. Then people ate the seed that they had reserved for planting, and finally left their homes on a desperate trek to some refugee camp where food-aid handouts might or might not be available. However, Ethiopia was not the only country affected. Harrison (1987, p. 18) summed up the situation.

In March 1985, the peak of the crisis, it was estimated that 30 million people were hit by the drought. Ten million of them were forced to abandon their homes in search of food. Up to 24 countries were simultaneously affected, in a vast scythe stretching from Mauritania across the Sahel to Somalia, down East Africa to Mozambique, and back across to the west coast in Angola.

Although more normal rains in the following years allowed many people to resume their usual lives, the underlying problems that had been brought to a head by the drought did not go away. Even though total food production increased slightly, this was not sufficient to keep pace with population growth, so that long-term food production per person continued to fall. The statistics indicate that at least 33 out of 38 tropical African countries underwent this decline in food production; in 7 of them, production per capita had decreased more than 20% since 1970. Harrison (1987, p. 21) concluded:

Economic mismanagement, prolonged drought, and warfare played a part in these cases — but only in intensifying a general trend. Even in the most favoured regions of Africa, food production per person fell by 8% between 1969–71 and 1981–82. Whereas Latin America and Asia have become almost self-sufficient in cereals, Africa has grown more and more dependent on imports and food aid. Back in 1963 she grew no less than 96% of her cereal requirements. 1985, the year the drought broke, saw Africa's biggest cereal harvest ever, yet it met only 78% of her much-expanded needs.

In 1991/92, both northern and southern Africa were again affected by drought and famine. Ethiopia, Somalia, and Sudan were the worst-hit countries in the north, with civil wars in Somalia and Sudan impeding the supply of food aid, so that many people died. In southern Africa, Angola, Botswana, Malawi, Mozambique, Zambia, Zimbabwe, and even South Africa were all affected to varying degrees and all these countries had to import large quantities of food, or receive food aid for people in the worst-affected areas.

Although the accuracy of the national statistics on food production that are quoted by the Food and Agriculture Organization of the United Nations (FAO) and others may be questioned, there is no doubt that malnutrition and poverty are widespread and increasing. The statistics indicate that millions are suffering from severe malnutrition. Malnourished people are particularly susceptible to the many diseases and parasites that are prevalent in Africa. Children, being the most vulnerable, suffer most — one of every eight dies from a combination of disease and malnutrition before its fifth birthday, and many more are physically and mentally impaired (UNICEF 1983).

No one who has money ever needs to go hungry, however, so hunger is itself a symptom of a deeper problem — poverty.

Poverty

It is well known that many of the world's poorest countries are in Africa. The World Bank (1995, table 1) reported that, in 1993, no fewer than 30 African countries had average annual incomes per person below US $700 (gross national product [GNP] per capita — see Appendix A). In 12 of these countries, incomes per person actually declined over the period 1987 to 1993, in some cases to less than 50% of their 1987 levels. The overall continent-wide average income per person was US $330. The 10 poorest countries are shown in Table 1.

Table 1. Gross national product (GNP) per capita of the 10 poorest countries in Africa, 1987 and 1993.

Country	Area ('000 km²)	Population (millions)		GNP per capita (US$)	
		1987	1993	1987	1993
Mozambique	802	14.6	15.1	170	90
Tanzania	945	23.9	28.0	180	90
Ethiopia	1097	44.8	51.9	130	100
Zaire	2 345	32.6	NA	150	NA
Sierra Leone	72	3.8	4.5	300	150
Burundi	28	5.0	6.0	250	180
Uganda	236	15.7	18.0	260	180
Malawi	118	7.9	10.5	160	200
Chad	1284	5.3	6.0	150	210
Rwanda	26	6.4	7.6	300	210

Source: World Bank 1989 and 1995, table 1.
Note: NA = not available.

Other than these 30 countries, 5 middle-income countries had an overall average income per capita of US $1426. Only Gabon and Mauritius exceeded US $3000. These figures can be compared with an average GNP per capita of $23 090 in the high-income economies.

McNamara (1985, p. 3) and the World Bank (1981, 1984, 1989, 1995) have documented recent trends in GNP per capita in Africa. Until about 1970, GNP per person increased steadily at a low average rate of about 1.4% per year, then the increase slowed in most countries in the 1970s, and a rapid decline, averaging 3.6% per year, took place from

1980–84, continuing in many countries into the 1990s. At the same time, the costs of food imports in current dollars rose sevenfold from US $1.9 billion in 1970 to US $12.4 billion in 1985.

Although some food imports were provided on concessionary terms as food aid, most had to be paid for at prevailing world prices using scarce foreign exchange. At the same time, prices of other imports were rising. The steep oil price rises in 1973 and again in 1979 added to foreign exchange costs, and drove up local prices.

McNamara (1985, p. 4) commented as follows.

Why are Africa's economic growth rates falling? Some would say that the continent's present problems are the result of external economic conditions that it has neither caused nor could change. And to a degree that is, of course, true. Despite its differences and relative remoteness from the more industrialized areas of the world, the continent has not been able to escape the turbulence of the international economic environment of recent years: the persistent recessions; the severe decline in commodity prices; increasing protectionism (which has been particularly damaging to two of Africa's major exports, sugar and livestock); the high real interest rates; and the decreasing net capital flows.
All of this is the price of living in an interdependent world. Distance no longer isolates Africa, or virtually anywhere else, from major international economic currents.
But it is not true that Africa is simply the hapless victim of impersonal economic forces over which it has no control. Other regions, facing similar outside forces, have suffered far less. Africa's present difficulties have not been imposed on it exclusively from the external environment. Like all newly developing societies, the countries of sub-Saharan Africa have had to wrestle with their own internal economic distortions, and they have made their own share of mistakes.
There have been: inadequate trade and pricing policies, especially in agriculture; overvalued exchange rates that discriminate against exports; mounting fiscal deficits, and a variety of burdensome government interventions and controls on the production process. Such policies, by and large, have pervaded sub-Saharan Africa for decades. They have exacted the inevitable penalties: an erosion of productivity, pragmatism, and entrepreneurial energy. And that, inevitably, has translated into sluggish economic growth.

Traditional Farming Systems

Most of the people of Africa depend directly on the land for their living. Although Africa's cities are growing at 5.3% per year, the fastest rate in the world, 71% of the people still lived in the rural areas in 1980. Nearly all these people depended for their livelihood on smallholdings of less than 10 ha (Harrison 1987, p. 23).

In the past, most of Africa was not densely populated, so cultivators were able to use the land extensively. They could choose the most fertile land, grow their crops for a few years and, when the soil fertility and crop yields declined, move to more fertile land. These farming systems, often described as "shifting cultivation" or "slash and burn" systems, were able to provide sufficient food and other products to satisfy the cultivators' needs in most seasons while maintaining soil fertility over the long term. Therefore, they were sustainable farming systems in those conditions.

Decline in Soil Fertility

As the population in a particular area increased, more of the land had to be cultivated for longer periods to satisfy the peoples' needs. The danger came when the number of people depending on a particular area of land (the population pressure) became too great for the carrying capacity of that land using existing technology. The considerable evidence that this is happening in many parts of the continent is examined in later chapters. This phenomenon is not new, nor is it confined to Africa. For example, Bennett (1939), who had an immense effect on the huge problem of soil exhaustion and erosion in the United States in the 1930s, has described the same process occurring down the ages and throughout the world.

Breakdown of Traditional Farming Systems

My aim here is to consider the possibility that the critical problem in Africa is that although smallholder farming systems are changing and adapting to increasing population pressures, in most areas they are not changing fast enough. The cultivator's response to declining soil fertility often appears to be to attempt to enlarge the cultivated area, even though a shortage of fallow land may mean that the fallow period must be shortened. The result is that soil fertility is further reduced and the vegetative cover on the soil surface is degraded, allowing erosion to accelerate so that soil fertility declines progressively and erosion damage increases. Destruction of forests or woodlands is often part of this process, which is unsustainable. Eventually, the soil productivity may decline to a low level, or even to near zero.

If this happens, the cultivator may try to respond in a number of ways: first, by changing the cropping system to increase the proportion of crops such as cassava that tolerate low soil fertility. If this fails to produce the necessary subsistence food, eventually the traditional shifting cultivator's path may be followed and the worn-out land abandoned and more fertile land elsewhere selected.

Alternatively, if the cultivator cannot find more fertile land, the farming practices may be intensified by increasing the use of manures and fertilizers, by growing additional crops on the same land, and practicing simple soil conservation and other techniques that conserve and build up soil fertility.

At present, the main responses of most cultivators seem to lie in the former directions, and the rate of change toward intensification appears to be too slow to provide the needs of the increasing populations.

My hypothesis is that this is the most crucial problem for the future of Africa. It is considered in more detail, together with some approaches to possible solutions, in later chapters.

The African Savanna

I have selected the savanna zone for closer examination because it is widely considered to be the zone at greatest risk of declining agricultural production at present, and parts of it have been severely affected by drought and food shortages in recent years. At the same time, the parts of the savanna that receive adequate rain have an enormous potential for the expansion of rainfed agricultural production (Higgins et al. 1982).

Book Outline

Part I of this book, in addition to this introduction, outlines the physical environment of Africa (Chapter 2) and reviews some characteristics of African farming systems (Chapter 3). Part II describes the African savanna and the bioclimatic approach adopted (Chapter 4). It then discusses selected farming systems of the Arid Savanna Zone (Chapter 5), the Subarid Savanna Zone (Chapter 6), the Subhumid Savanna Zone (Chapter 7), and the Humid Savanna Zone (Chapter 8). Part III gives the conclusions of the study in four chapters: the Physical Environment (Chapter 9), Farming Systems (Chapter 10), Agricultural Research (Chapter 11), and Future Prospects (Chapter 11).

Chapter 2: The Physical Environment

In recent years, the international community has been increasingly interested in environmental problems worldwide, including the destruction of tropical rainforests and other wooded areas, accelerated soil erosion, and pollution. The Earth Summit, held in Brazil in 1992, served to focus the world's attention on these and other problems. One of these problems has been the decline in food production in Africa since the late 1960s, particularly in the savanna region. My study shows that the main cause of environmental deterioration in the African savanna is the breakdown of savanna farming systems.

Because a considerable amount of information on the African environment is available elsewhere (see, for example, Russell 1962; Harrison Church et al. 1965; Kowal and Kassam 1979), I have confined this chapter to those aspects that are critical to farming systems. These are climate and soils. Topography is also important, but it is too location specific to be considered for the whole of the savanna areas, so it is considered with each farming system. The indigenous natural vegetation develops as a result of the interaction of climate and soils, and is discussed briefly under each bioclimatic zone. However, the main emphasis in this study is on the existing vegetation, which is largely the effect of humans and their domestic animals on the natural vegetation.

Climate

Climate is the main determining factor for agriculture in Africa, as indeed throughout the world. In temperate regions, low winter temperatures limit active growth to a summer season of a varying length, but in tropical Africa, with the exception of certain highland areas, temperatures are generally high. Thus, the main determinant of crop growth is rainfall, except in the limited areas where irrigation is practiced. Even these irrigated areas depend on rainfall to recharge the rivers or groundwater reserves from which irrigation water is obtained.

Rainfall

Rainfall in the tropics depends mainly on the movements of the air masses that cover the globe (Cochemé and Franquin 1967). The sun is over the equator on 21 March, the tropic of Cancer on 21 June, the equator again on 21 September, and the tropic of Capricorn on 21 December. The sun's heat causes a low-pressure zone that encircles the earth roughly parallel to the equator, and that moves north and south following the sun, usually with a lag of 4–6 weeks. This zone is often called the Inter-Tropical Convergence Zone (ITCZ).

Figure 3 shows the rough location of the ITCZ over Africa in January and July. As the air is heated in this zone, it rises, forming clouds and rain. North and south of the limits of movement of the ITCZ are the high-pressure belts that also encircle the earth.

Distribution: The equatorial region, which is crossed by the ITCZ twice a year, is mainly a zone of high rainfall, particularly in west and central Africa, where westerly winds bring rain from the Atlantic Ocean (Fig. 4). For the same reason, this zone has relatively well distributed rains throughout the year, although they tend to fall in two rainy seasons — from about March to June and from August to November — separated by two short dry seasons. Further north and south, as the ITCZ moves toward its limits, the rains become confined to a single rainy season that becomes shorter in duration and more limited in amount and reliability with increasing distance from the equator, until the desert zones are reached where little rain falls — the Sahara in the north and the Kalahari in the south.

Variation: One of the most difficult factors with which farmers must contend, particularly in the semi-arid areas, is rainfall variability. Although farmers always have some traditional rough and ready knowledge of rainfall patterns in their own areas, they may often be taken by surprise by changes in the "normal" rainfall patterns, particularly if a run of wet years is followed by several dry years, as happened throughout semi-arid Africa in the early 1970s, the 1980s, and again in 1991–92.

It appears that although the movements of the ITCZ following the sun are relatively predictable, there are variations in its rate of movement. When its movement northward or southward is delayed, and it does not reach as far north or south as normal, the rainy seasons are late starting and there may be less than average rainfall, particularly in the semi-arid regions. These variations have enormous effects on farming systems, particularly in the drier areas. The reasons for these variations do not appear to be understood at present, and would seem to deserve considerably increased research effort.

There has been much discussion of possible long-term downward trends in mean rainfall in semi-arid Africa, but Pereira (1981, p. 6) points out that

Two of the world's major meteorological computer centres, at Bracknell in Britain and at Boulder City in USA, have made very thorough studies of the world data. They have detected no evidence of overall significant trends during the past 200 years, either in the means of climatic values or in variability about these means.
Notwithstanding these comments, some observers have identified signs of a decline in savanna rainfall over the last 35 years. More rigorous analysis of long runs of rainfall data is needed to try to determine trends and cyclical or other patterns. One way of approaching this need is to calculate rainfall probabilities for recording stations where adequate data is available. A start was made on this by Manning (1956), and continued by other workers in East Africa, by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT 1989) for the Sahel region, by Le Houerou and Popov (1981) for sub-Saharan Africa, and by the International Council for Research in Agroforestry (ICRAF 1989) for agroforestry applications. The World Meteorological Organization (WMO) is active in developing methods for the standardized recording and communication of weather data.

Intensity: Kowal and Kassam (1979) gave a useful summary of information on rainfall intensities in the West African savanna. Working at Samaru, northern Nigeria, they found that peak rainfall intensities of 120–160 mm/hour were not uncommon. Analyzing the data from several seasons, they found that storms with less than 20 mm rainfall did not produce any runoff on cultivated areas of gentle slope, whereas all storms of over 20 mm rain produced some run off, the amount depending on the rainfall duration and intensity. On this basis, 32 storms containing about 58% (635 mm) of the seasonal rainfall fell in storms of over 20 mm and were erosive, and 53 storms containing about 42% fell in storms of less than 20 mm and were nonerosive. An analysis of the seasonal distribution of the storms indicated that because the number of storms was correlated with the amount of rainfall, a greater number of erosive storms fell during the three wettest months — July, August, and September — than throughout the remainder of the rainy season. They concluded that

The intensity of rainfall and energy load of individual rainstorm systems in the West African savanna is much greater than that of temperate and subtropical rainstorms and presents special problems in agricultural management and land conservation.
Charreau and Nicou (1971) found that 25% of the rainfall at Bambey, Senegal, fell at intensities of over 50 mm/hour, and they recorded intensities up to 740 mm/hour over short periods in occasional heavy storms. Charreau (1974) pointed out that, on average, tropical rains have 6–10 times more erosive power than temperate rains.

On the other hand, although total rainfall may increase in the highlands with increasing altitude, intensities and therefore erosivity appear to decrease. For example, Thomas et al. (1981) working at an altitude of 1500–2000 m at Isuni in Machakos District, Kenya, only recorded five storms with intensities greater than 25 mm/hour (for a 15-minute duration) out of 30 storms recorded during November and December 1978. They concluded that

Isuni was located in an area of low erosivity. Fournier (1962) has produced a map showing the expected erosion hazards throughout Africa.

Hudson (1981, p. 78) concludes that

The vital difference is that in temperate rainfall something like 95% of the rain falls at low non-erosive intensities, i.e. only 5% is heavy enough to cause erosion, whereas in the case of tropical rainfall only 60% falls at intensities less than 25 mm/hour, and the remaining 40% contributes to soil erosion.
Although detailed information is still lacking on both the erosivity of the rains and the erodibility of the soils in many parts of Africa, it is clear that the risks of accelerated erosion are very high in these areas. These are discussed further in the section on soils.

Solar Radiation, Temperature, Evaporation, and Evapotranspiration

Solar radiation provides energy in the form of light and heat, which also fuel evaporation and evapotranspiration. Incoming solar radiation at the top of the atmosphere is relatively constant in the tropics, but global radiation reaching the earth's surface is greatly affected by cloud, particularly in the more humid regions. For example, it varies from over 2400 kJ/cm^2 per day in the desert to below 1500 kJ/cm^2 per day at the southern edge of the West African savanna. The annual range in day-length varies from nil at the equator to nearly 2 hours at 17°N or S (Okigbo 1986, p, 97).

Temperatures in tropical lowland areas are generally high, with averages near the equator at sea level of about 30°C and a diurnal variation of about 11°C. There is a small reduction in temperature of up to about 6°C during the rainy seasons as a result of cloudiness. There is a small but increasing seasonal variation in monthly mean temperatures with increasing distance from the equator. For example, at Asmara in northern Eritrea (latitude 16°N), the warmest month, May, is about 5°C warmer than the coolest month, December, but during the rains in August, the temperature is reduced by about 3°C to little above the December level.

The highland areas have considerably lower temperatures with increasing altitude, so that the higher altitudes in effect have temperate climates, but with little seasonal variation. On average, the rate of fall in temperature with increasing altitude (lapse rate) is about 0.6°C per 100 m, but local variation is considerable (Brown and Cochemé 1969, p. 217).

Evaporation is a function of solar radiation, temperature, wind, and humidity. Evaporation from open water surfaces varies from less than 100 mm/month during the rains in the more humid areas and at the higher altitudes to about 200 mm/month during the hot dry season in the arid regions at low altitudes.

Evapotranspiration is the sum of evaporation from the soil surface and transpiration by plants. Because plant growth and production are normally limited if transpiration is reduced, the farmer tries to ensure that transpiration is not constrained by lack of soil moisture, particularly during critical periods for crop growth. In view of soil moisture limitations throughout semi-arid Africa, it appears essential to intensify research on all aspects of soil moisture conservation and evapotranspiration. <cebter>

Soils

Soil Classification

Several different systems have been used for classifying the soils of various African countries. These are too numerous to detail, but the French system (Aubert 1968) and the Belgian system (Sys et al. 1961) are two of the most important. Useful reviews of the soils of West Africa are contained in Ahn (1970) and Jones and Wild (1975). East African soils are reviewed by Scott (1972). The FAO soil map of Africa (D'Hoore, 1964) and the African section of the later FAO and Unesco (1974) soil map of the world represent attempts to draw together the available information on African soils. Sanchez (1976) gives a good summary of information to that date on tropical soils.

Although considerable research and detailed mapping have been carried out on the soils of several countries, there appears to be a need for a much greater and more sustained research effort to classify and determine the characteristics of African soils, and particularly to work out improved methods of soil management and conservation that can be applied by smallholders.

Because the US system of soil classification (that is, soil taxonomy, USDA 1975) seems to be gaining increasing acceptance worldwide, the map of African soils used here (Fig. 5) represents a first approximation of the application of this system to African soils (Aubert and Tavernier 1972).

Although considerably more work needs to be done on the adaptation of the soil taxonomy classification system to African soils, there appear to be substantial advantages in its use to allow comparisons between African soils and other similar soils worldwide. Although a map on this large a scale obviously has a limited value for any detailed discussion of agricultural uses, certain broad generalizations may be attempted following Sanchez (1976) and Ahn (1970, p. 220).

Because rainfall and soil moisture are critical for tropical farming systems, as has already been stated, the soil taxonomy system uses the following terms that are important for savanna soils:

- Udic — On average, water stress is absent during most of the year;
- Ustic — A strong dry season of 3–6 months;
- Aridic — A longer dry season: dry and desert climates; and
- Aquic — The soil is saturated with water long enough to cause reduced soil conditions.

Alfisols: The map indicates that the soils over vast areas — estimated at 550 million ha (Sanchez 1976, p. 73) — of the African savanna are classified as alfisols. These are a varied group. They have an argillic (clayey) horizon with more than 35% base saturation. They are similar to ultisols except for a considerably higher natural fertility level.

Oxisols: Oxisols are widespread in the high rainfall areas of the Congo basin and extend through Zambia, Mozambique, and neighbouring countries into Madagascar. They are estimated to cover roughly the same area as the alfisols, about 550 million ha.

These highly weathered soils are defined as having oxic horizons (above 16 meq/100 g clay), consisting of mixtures of kaolinite, iron oxides, and quartz, that are low in weatherable minerals. These soils are usually deep, well-drained red or yellow soils with excellent granular structure, very low fertility, and uniform properties with depth.

Ultisols: Ultisols are mainly found in relatively humid areas such as Guinea, Liberia, Uganda, and parts of eastern Zaire. They are estimated to cover about 100 million ha.

Ultisols are defined as having an argillic horizon (20% increase in clay content in the control section — roughly the main rooting zone) with less than 35% base saturation in this zone. They are usually deep, well-drained red or yellow soils, higher in weatherable minerals than oxisols, with less desirable physical properties, and relatively low natural fertility. Ultisols may have oxic horizons above or below the argillic.

Entisols: Entisols are widespread in the drier areas of south-west Africa, stretching northwards through Angola into Zaire and covering roughly 300 million ha.

They are pedologically young soils in which the horizons are only slightly developed or undeveloped. They include many recently deposited alluvial materials and some young soils on inert and resistant parent materials.

Inceptisols: The inceptisols occur mainly in the Central African Republic and part of the southern Sudan with an estimated area of 70 million ha.

They are slightly more developed than the entisols with a cambic horizon but no other diagnostic horizons, and are also relatively young. They are not strongly weathered, and include some poorly drained gley soils without well-developed horizons, and some volcanic soils.

Vertisols: The largest area of vertisols is in the Sudan and parts of Ethiopia, however, they are fairly widely distributed, mainly in valley bottoms, throughout Africa. Their area is estimated at 40 million ha.

These are a unique group of soils, often described as black cotton soils. They are heavy, usually dark coloured, clay soils that form deep cracks when they dry out. Because of the high clay content (over 35% clay containing over 50% of 2:1 — mainly montmorillonitic — clay minerals), they are difficult to cultivate when dry, and become very sticky when wet.

Aridisols: As the name indicates, these are soils of arid regions such as the Sahara and Kalahari deserts. At 840 million ha, they cover the largest area of the soil groups in tropical Africa, but because much of this is desert they are less important in the savanna areas. They show some horizon differentiation.

Geomorphology

Although the soil map (Fig. 5) attempts to show some of the dominant soil types, it represents an oversimplification of a more complex situation. Most of Africa is underlain by a vast shield of ancient Precambrian granitic rock. This shield has been lifted up and eroded down repeatedly over geological time, and parts of it have been submerged under seas or lakes for varying periods, leaving sediments over the granite. As a result, Africa has a very varied topography, but many areas could be described as having a rolling landscape. These repeated hills and valleys have characteristic patterns of soils, depending on the underlying parent materials.

Milne (1935), working in Tanzania, proposed the term catena for these patterns of soils, which often repeat themselves up and down the hills over thousands of kilometres. Such a catenary sequence is shown in Figure 6. Gravelly red and brown upland sedentary soils are found at ***A*** and ***B*** on summits and upper slopes. These grade downslope into yellow-brown, sandy, light, clay soils developed in middle-slope colluvium at ***C*** and into yellow-brown, sandy loam and loamy sand colluvium at ***D***. The soils developed in local granite-derived alluvium at ***E*** are mostly grey to white sands with subordinate areas of gritty or sandy grey clays.

This diagram indicates how the granitic soils on the hilltops with characteristic ironstone gravel at varying depths have been eroded downhill forming the colluvial soils on the slopes and the grey or white sandy or grey clayey alluvial soils in the valley bottoms. Needless to say, there are innumerable variations both in the underlying materials and in these patterns of soils.

Savanna Soil Characteristics

Kowal and Kassam (1978) have commented in detail on the characteristics of the soils of the West African savanna. The following brief summary draws heavily on their synthesis.

Soil Depth and Structure: Kowal and Kassam (1978) emphasize the critical importance of soil depth, because of the widespread presence of ironstone gravel or plinthite in many savanna soils, which can restrict root growth at varying depths and interfere with cultivation. They also stress the sandy nature of most savanna soils, although some of the leached alfisols and ultisols contain increasing amounts of clay, mainly kaolinitic, in the deeper horizons. They point out the importance of soil structure and surface characteristics, particularly when the vegetative cover is removed, so that the soil surface is exposed to heavy rain, and capping (crusting) often takes place. Jones (1987, p. 12) also noted soil capping as a major problem on apparently similar soils in Botswana.

Many savanna soils are fine sandy loams, with high bulk densities that can restrict root growth. On these soils, plowing or deep digging gave crop yields between 20–70% higher than those obtained after shallow hoeing, with an average increase of 24% (Charreau 1974; see also Pingali et al. 1987, p. 62).

Soil Moisture: Soil moisture deficiency is one of the primary limiting factors to crop growth in the drier savanna areas. Even in the more humid areas, the seasonal distribution of rainfall described earlier is an important determining factor for crop growth, depending on the moisture-storage capacity within rooting depth of the particular soil. This depends on the depth, organic matter (OM) content, structure, and texture of the soil, particularly the clay content. Moisture storage in the top 1 m of soil varies from about 80 mm in sandy soils to about 150 mm in soils with a higher clay content.

Time of planting and crop-growth duration need to be closely fitted to the expected moisture supply for the rainy season. Ways in which farmers can make these adjustments are discussed in more detail in later sections.

Cation Exchange Capacity: The effective cation exchange capacity (CEC) of many savanna soils is low, often below 4 meq/100 g, and is closely related to the OM and clay contents of the soils, many of which have a variable charge (Sanchez 1976, p. 155). CECs can be increased by liming acid soils and increasing OM contents. The implications of this and other changes in soil reaction (pH) are discussed further in a later section.

Organic Matter: Organic matter is of critical importance in savanna soils. Under a thick cover of forest, bush, or even grass fallow, OM increases, the soil surface is protected, and soil temperature is moderated, the CEC is maintained, soil organisms such as earthworms are active (Lal 1983, p. 20), and within the limits of the soil's inherent fertility, productivity is high. Once the vegetation is burned, or the soil is cultivated, soil OM breaks down rapidly, depending on the moisture content. The rate of breakdown is proportional to the temperature (Birch and Friend 1956).

Lal (1983, p. 14) and others (for example, Sanchez 1976, p. 105) have emphasized the critical role of mulching in tropical crop production. Mulches decrease the energy of raindrops and therefore protect the soil from capping and erosion, they limit evaporation and therefore retain soil moisture, reduce the rate of OM decomposition, prevent excessively high soil temperatures, which can impede or prevent seedling emergence, increase soil water storage, and decrease weed infestation. As they decompose, mulches make OM and nutrients available for crop growth. In many areas, farmers traditionally practice mulching using crop residues or uprooted weeds. Crop yields can often be substantially increased by mulching (Table 2).

Table 2. Effect of mulch and fertilizer on yield (kg/ha) of cotton in Zaire.

Year	Without fertilizer	With fertilizer

	Unmulched	Mulched	Unmulched	Mulched
1947–48	1032	1127	–	–
1953–54	200	1117	440	1434
1955–56	186	1464	797	1977
1956–57	124	986	706	1344
Source: Adapted from Jurion and Henry (1969).				

Kowal and Kassam (1978, p. 103) point out that the effects of OM on soil fertility in tropical soils continue to arouse considerable controversy. However, it appears clear that, on many tropical soils, the addition of OM can give substantial yield increases, and can allow economies in fertilizer applications.

In recent years, there has been a considerable increase in so-called "Organic Farming" throughout the world. Farmers using this method aim to maintain or even increase the OM content of the soil by applying manures, crop residues, and mulches. In this way, they claim to be able to reduce their need for inorganic fertilizers. Some of them refuse to use "artificial" fertilizers, pesticides, and other products. There seems little doubt that when these methods are applied consistently over long periods, soil fertility does build up, and crop yields are often improved. On the other hand, the soil nutrient balance-sheet must be maintained. If the soil is inherently low in nutrients, it may take very large quantities of OM to provide for the needs of heavy yielding crops, particularly if these crops are sold off the farm so that most of their residues cannot be returned to the soil.

Provision of this OM can be very laborious and expensive for the farmer. To help overcome this problem, some "organic farmers" are willing to use "natural" fertilizers such as phosphatic rock. In some western countries, householders worried about the effects of pesticide residues in food are willing to pay increased prices for "organically" grown foodstuffs. These higher prices can give an incentive to farmers to use "organic" methods.

Because of the labour and expense involved in providing either sufficient OM or fertilizers for many savanna farming systems, it is considered of critical importance that more research should be directed to the investigation of appropriate combinations of added OM and fertilizers for tropical crop production.

Nutrients

Phosphorus: Phosphorus deficiencies are widespread in savanna soils, and many authorities consider lack of phosphorus to be the primary nutrient limiting crop production in the savanna (Kowal and Kassam 1978, p. 143), although nitrogen may be the limiting nutrient in the wetter savanna areas (Sanchez 1976, p. 184). Average phosphorus contents in surface soils range from about 80–150 ppm, which are very low compared with temperate soils that have average contents of about 1500–3000 ppm. Part of the soil phosphorus is in the form of organic phosphorus, but this tends to be low in most savanna soils (15–60 ppm, Goldsworthy and Heathcote 1963). Losses of phosphorus from soils by leaching are generally low, but much of the soil phosphorus is held by the soil in various ways making it only slowly available to crops. However, phosphorus fixation is not usually a serious problem in the more sandy savanna soils, although it can be a constraint in some of the heavier acid soils in East Africa and elsewhere.

Many African countries have naturally occurring deposits of phosphatic rock, and some of these deposits are being developed for both local use and export. For example, Senegal and Togo export considerable quantities of phosphate, and Senegal uses some of its production locally. These phosphatic rock deposits vary greatly in the percentage of phosphorus and in its form and availability. The location of some of the deposits is remote, and this determines the ease of extraction and transportation. For example, Mali has started developing a deposit at Tilemsi in the Sahara desert north of Gao, and trials have shown that finely ground phosphatic rock from this deposit can be applied directly to crops with promising results, particularly on the more acid soils. The deposits in Burkina Faso, Niger, and Togo, on the other hand, appear to require processing to increase solubility before use.

Because phosphorus, unlike nitrogen and other nutrients, does not move much in the soil, and it is especially required for early root growth, it is important to ensure that phosphorus fertilizers are placed close to seeds, particularly in soils that fix phosphates. This can be done by using a placement drill for planting, or phosphate rock can be mixed with the seed for hand-planting. (Some types of fertilizer may damage the seed or young plants if placed in contact with the seed at planting. These can be put into the planting hole and covered with soil before planting the seed.)

Nitrogen: Nitrogen deficiencies are widespread in savanna farming systems, and are often limiting factors to crop growth (Sanchez 1976, p. 184). The most important source of nitrogen is from biological nitrogen fixation (BNF) from the atmosphere. When leguminous plants or crops are present, Rhizobium bacteria symbiotic in the roots are the main source, but other sources include free-living nitrogen-fixing bacteria in the leaf canopy, the litter, and the rhizosphere, and bluegreen algae, particularly in flooded rice fields. Traditional cropping systems where cereals such as sorghum or millet are intercropped with leguminous crops such as cowpeas or groundnuts appear to assist in reducing nitrogen deficiencies in one or both crops (Greenland 1985, p. 19).

The nitrogen status of unfertilized soil is closely associated with the soil OM, and therefore varies with the OM content. Also, Hardy (1946) and Birch (1958) showed that the alternate wetting and drying associated with the first rains produce a flush of mineral nitrogen in a previously dry soil containing OM, because of the action of microorganisms as the OM decomposes. This important phenomenon is sometimes called the "Birch Effect." The amount of mineralized nitrogen varies, but it can be as much as 70 kg N/ha after manuring. Unlike phosphorus, nitrogen can be lost rapidly from the soil by leaching or by volatilization from the soil surface. These losses can be reduced by early planting of crops, so that the crops can take up some of the mineralized nitrogen before it is lost by leaching. Volatilization can be reduced by incorporating the fertilizer into the topsoil. Another way of reducing the losses is by careful timing of fertilizer nitrogen applications, usually about 2–6 weeks after planting (Charreau 1974).

Potassium: Although potassium deficiencies have been reported on certain soil types under heavy cropping, in general they do not appear to be limiting to crop production in most savanna regions (Nye and Greenland 1960, p. 99). Like phosphate, potassium is returned to the soil in crop residues or other forms of OM, and in the ash after burning, so it is easily recycled, but leaching losses can be severe. Also, although savanna soils are often comparatively low in potassium, the nutrient appears to be readily available in most tropical soils. However, under continuous heavy cropping with the removal of crop residues, potassium could be expected to become limiting to the yields of a number of crops, depending on the CEC and pH of the soils, therefore a careful watch needs to be kept for deficiency symptoms. This does not imply that the uneconomic use of compound fertilizers containing potassium as well as nitrogen and phosphate is justified, however, unless there is strong evidence of the likelihood of potassium deficiencies.

Acidity, Aluminum Toxicity, and Calcium and Magnesium Deficiencies: Many savanna soils are acid, particularly in the more humid areas, and in these soils aluminum toxicity is a major limiting factor to the growth of susceptible crops. These crops include many leguminous species such as groundnuts and soybeans. Maize, sorghum, and many others are also susceptible to varying extents. In contrast, crops such as cassava and coffee can tolerate a certain degree of acidity. The low CEC of most savanna soils limits the amount of exchangeable calcium and magnesium to about 0.3–3.0 meq/100 g. In crops growing on soils in dry areas, it is often difficult to separate the detrimental effects of lack of calcium or magnesium as nutrients, and the indirect effect of aluminum toxicity (Kowal and Kassam 1978, p. 148). Under traditional shifting cultivation on soils with pH above about 5.5, there is little evidence of much crop response to liming (Nye and Greenland 1960, p. 97). On more acid soils, and on savanna soils under more intensive cropping with heavy use of nitrogenous fertilizers, the pH may often fall below 5.5, and liming may be necessary, although surprisingly few experiments appear to have been conducted on this important topic in the African savanna.

Small applications of 1–2 t/ha of lime once in 5–10 years often appear sufficient to raise the soil pH to 5.5, and to prevent aluminum toxicity, and they may give quite large yield responses, particularly in maize, sorghum, and legumes such as groundnuts. For example, it has been estimated that about 20% of the cultivated land in Senegal needs liming to correct acidity and prevent aluminum toxicity (Pieri 1974). On the other hand, overliming the soil to above pH 5.5–6.0 can reduce yields by lowering the availability of phosphate and other nutrients (Sanchez 1976). Most African countries have lime deposits that could be used for this purpose. Although the costs of extraction and transport could be quite high for subsistence cultivators remote from the sources, as cropping intensities increase it would appear essential that greater attention should be paid to this type of amendment.

Sulfur: Sulfur is mainly contained in OM and, like nitrogen, it is lost to the atmosphere when crop residues or bush or grass fallow are burned. Because OM levels are generally low in savanna soils, sulfur deficiencies are widespread, particularly in areas remote from the sea or from smoky industries, where the rain usually contains some sulfur (Nye and Greenland 1960, p. 97). Where fertilizers containing sulfur — such as ammonium sulfate or single superphosphate — are used, little sulfur deficiency occurs, but the increasing use of low sulfur fertilizers — such as urea and triple superphosphate — can result in sulfur deficiency in susceptible crops. Small dressings of up to 20 kg S/ha are sufficient to correct this (Kowal and Kassam 1979, p. 148).

Micronutrients: Occasional deficiencies of micronutrients such as boron, molybdenum, and zinc have been identified, particularly on plantation crops, and on cotton and groundnuts under heavy cropping. Boron is sometimes routinely added to cotton fertilizers, but care must be taken to avoid toxicity, because the margin between deficiency and toxicity is narrow.

Manganese is also an essential nutrient, but it is more likely to become toxic, like aluminum, on certain acid soils. This can be corrected by liming (see above).

Soil Erosion

It is generally recognized that the greatest threat to sustained rainfed agricultural production, and indeed to the continuing prosperity of many of the developing countries in Africa and elsewhere, is probably uncontrolled soil erosion (Hudson 1981). For example, Brown and Wolf (1985) have suggested that about 1 billion t of top soil are being lost by erosion each year in Eritrea and Ethiopia alone. Although the basis for such estimates is not clear, there is no doubt that uncontrolled erosion is causing enormous damage to the soils of Eritrea, Ethiopia, and most other African countries.

As population and land pressure increase, uncontrolled erosion is depleting valuable topsoil, undermining roads and other structures, and causing floods and silting of reservoirs throughout Africa. Yet surprisingly little scientific data on erosion is available from large areas of Africa. Kowal and Kassam (1978) have attempted to summarize the situation in the West African savanna. They point out that, in the higher rainfall areas of the Guinea and Sudan savannas, water erosion is the most important cause, whereas in the Sahel, although water erosion can be severe in the southern subregion during the occasional storm, wind erosion also occurs and is particularly severe in the north.

Erosion Caused by Rain: Under natural vegetation undisturbed by humans or domestic animals, the soil surface is normally protected by leaf litter and a canopy of leaves, and negligible erosion takes place. For example, Roose (1967) estimated the annual rate of soil loss under natural vegetation at Sefa, Senegal (1150 mm rainfall), as 0.1–0.2 t/ha. At Samaru, Nigeria, with a similar rainfall, Kowal and Kassam (1978) found that runoff and soil loss were negligible even when annual burning of natural vegetation was practiced. Because soil formation does occur, albeit very slowly, under savanna conditions, it is evident that the rate of erosion under natural vegetation is unlikely to be as great as the rate of soil formation, so a net gain in top soil occurs.

Erosion damage under traditional shifting-cultivation practices with low population pressures of humans and livestock is generally considered to be relatively limited (Sanchez 1976, p. 363). Shifting cultivators usually open small plots for 2–3 years, leaving the stumps of bushes and trees to regenerate during the fallow period, and maintaining a cover of vegetation or crops on the land during most of the rainy season. Even if some runoff and erosion does occur within the plot, it is usually arrested as soon as it reaches natural vegetation at the edge of the plot (Nye and Greenland 1960, p. 88).

The danger comes as population pressure causes an increasing proportion of the land area to be cultivated for extended periods, or large-scale mechanical cultivation is introduced (Lal 1974) so that soil fertility and the vegetative cover are reduced, and accelerated erosion can take place if careful precautions are not taken.

Accelerated Erosion: The most widely practiced method of calculating the water erosion hazard is by the use of the Universal Soil Loss Equation, which was developed by Wischmeier and his associates in the United States (Wischmeier and Smith 1978). This method combines information on the erosivity of the rainfall in a particular area with the erodibility of the soils, together with land and crop management factors to calculate the predicted soil loss.

Vegetation or Crop Cover: Roose (1977) has reported on many years of work on measuring erosion in francophone West Africa. For example, he measured erosion losses on a ferrallitic soil at Adiopodoumé, near Abidjan, Côte d'Ivoire, with an annual rainfall of 2138 mm (Table 3). One of the characteristics of erosion is its extreme variability depending on the particular conditions prevailing (Table 3). These data, with results quoted by Charreau (1974), indicate that the annual soil losses from cultivated fields under a wide range of conditions varied from about 0.1–138 t/ha: the higher value being more than 1300 times the lower. It is significant that the maximum soil loss that is considered tolerable in the United States is 11.2 t/ha per year (Hudson 1981).

Table 3. Annual soil loss by water erosion at Adiopodoume, Côte d'Ivoire.

Crops	Slope (%)	Soil loss (t/ha per year)	
		Range	Mean
Cassava and yams	7	22–93	32
Maize	7	35–131	92
Groundnuts	7	59–120	82
Bare soil	7	69–150	138
Bare soil	4.5	34–74	60
Bare soil	20–23.3	266–622	570

Source: Roose (1977, table 14).

In general, the extent of erosion is inversely proportional to the vegetative cover over the soil during the rainy season, whether in the form of natural vegetation, perennial crops, one or more annual crops, or leaf litter or mulch on the soil surface. It follows from this that perhaps the most important farming practices for the prevention of erosion are those that maintain an effective vegetative cover over the soil for the maximum time during the rainy seasons. This is considered in more detail in the next chapter, but at this point the importance of early planting of annual crops cannot be over stressed.

Soil Type and Structure: The erodibility of savanna soils, or their vulnerability to erosion, is generally high because many of the soils are sandy, low in OM, and of unstable crumb structure (Kowal and Kassam 1978, p. 168).

It appears that certain types of fine sandy loam or loamy sand soils that are low in OM through overcultivation, and therefore have unstable structures, are particularly liable to erosion because of their tendency to crust. When a high intensity rainstorm hits bare soil, the fine soil particles are loosened by rain splash and are washed down into the pore spaces, which quickly become blocked. Once the pore spaces are blocked, and the soil surface is saturated, runoff starts (Chase and Boudouresque 1989). The fine OM and lighter soil particles are the first to be removed by runoff: measurements show that the eroded material contains two to four times more of the fine particles containing nutrients than the original soil (Jones and Wild 1975, p. 65; Kowal and Kassam 1978, p. 171). On these soils, when the surface soil dries, the crust can become so hard that germinating seedlings of some crops cannot penetrate it. Also, further heavy storms can cause severe erosion because the crust causes most of the rain to run off instead of infiltrating into the soil (Ker et al. 1978, p. 39; Jones 1987, p. 12).

On the other hand, the coarse dune sands that are found in parts of the Sahelian and Sahara zones appear to have such high infiltration rates that little water erosion takes place. Instead, these soils are liable to erosion by wind (this is discussed later). Some of the soils of volcanic origin that occur in parts of East Africa appear to have such a stable crumb structure that their erodibility also seems to be comparatively low, except under the most severe storms.

Angle and Length of Slope: The amount and speed of runoff depend on the steepness of the slope. The scouring capacity of running water increases as about the fifth power of its velocity (Jones and Wild 1975, p. 62). Therefore, slow-moving runoff may cause little erosion, although it can reduce the amount of soil moisture available for plant growth. As the runoff picks up speed, it causes subrill erosion, which is the most widespread form of erosion damage, but is often difficult for the untrained observer to identify. This type of erosion gradually removes the most fertile topsoil, until only infertile subsoil remains. It is particularly serious where a shallow topsoil overlies an iron pan or concretionary layer. In some parts of Africa, all the topsoil has been removed by erosion, leaving massive plinthite, which is useless for agriculture, or ironstone gravel, which is almost as bad.

As runoff accelerates down the slope, it becomes concentrated into small rivulets, which cause rill erosion. This is easier to observe than subrill erosion and, on long slopes with inadequate protection, the water may eventually form gullies, which can cause severe damage.

Wind Erosion: Like water erosion, soil erosion by wind is only serious where there is no protective cover of vegetation. Wind erosion is particularly severe in the Sahara and Kalahari deserts and in the subdesert fringes (for example, the northern Sahelian Zone in West Africa), although it can occur elsewhere.

Although experimental evidence is lacking, there appears little doubt that an increase in wind erosion has occurred in these desert and subdesert areas as a result of the destruction of much of the natural vegetation. This destruction is mainly due to overgrazing by excessive numbers of domestic livestock. Damage to the tree cover has also been caused by the clearing of bush for increased cultivation and for firewood. Wind erosion seems to be mainly confined to the regions receiving less than about 500 mm mean annual rainfall because, in the higher rainfall areas, there is usually enough vegetation — sometimes in the form of crops — to protect the soil from serious wind damage (Roose 1989).

During the dry season in West Africa, the northeast trade wind — the Harmattan — often carries a cloud of dust that covers much of West Africa, even as far south as the Cameroon and Nigerian coast. There have been reports that West African dust has been identified as far from Africa as the West Indies and parts of Europe. Although this consequence of wind erosion may have occurred from ancient times, some observers consider that the quantities of dust carried in recent years may have increased, particularly during drought periods; however, few quantitative measurements seem to be available. Hudson (1981) has reviewed the subject of wind erosion in some detail.

Desertification: The Sahelian drought of 1968–73 aroused world-wide concern about the possible spread of the Sahara desert into the Sahel region, and perhaps further southward into the Sudanian region. This concern was extended to other parts of the world that were similarly affected. The United Nations conference on desertification, held in Nairobi in 1977, both attempted to summarize some of the available information on the subject and had the effect of arousing widespread interest.

Many widely varying estimates of the rate of spread of the Sahara have been published, but these do not seem to be derived from rigorous scientific studies. The arid area certainly fluctuates according to the rainfall, and particularly during a run of dry years such as occurred from 1968 to 1973, and again from 1979 to 1984, the arid area with its accompanying wind erosion extended southward. However, it is not clear what happens during a run of wetter years. Certainly, the vegetation makes some recovery in these drought-affected areas and, because the livestock population may have been reduced during the dry period by migration southward or by deaths, the vegetation has a chance to reestablish itself. However, when the herders move the livestock northward again and the herds regain their former numbers by breeding, the grazing pressure on the vegetation may again become heavy and the next dry period may lead to further damage, which may eventually become irreversible.

Current indications of global warming may also have substantial effects both on temperature and rainfall in Africa, but it seems too early to predict probable outcomes.

Soil Conservation: Because soil conservation must be an integral part of farming systems, it is considered in the next chapter on farming systems.

Chapter 3: Farming Systems

Over 70% of the people of Africa live in rural areas, and almost all of them depend directly on their smallholdings for a living. Although many people are moving to the cities, apparently mainly because they hope for a better standard of living there, it is common knowledge that even in the cities many people still try to cultivate small plots to obtain some of their food (see, for example, IDRC 1993). Thus, it is clear that farming is by far the largest economic enterprise in Africa, and it is vital for the well-being of most people.

Although no two farms are exactly alike, it is obvious to anyone who has traveled in the countryside anywhere in the world that most farms in a particular area usually have many common features. Depending on the environment in that area, most of them grow the same crops, keep the same animals, and go about their farming in roughly similar ways. Therefore, they can be said to practice similar farming systems.

Farmers have to adapt their farming to their natural environment — to succeed, they must work with nature and not against it. They must also adapt their systems to infrastructural factors, such as land-tenure arrangements, and the availability of inputs such as water, power, fertilizers, pesticides, labour, advice, and information. External economic factors such as location, availability of roads, communications, markets for selling produce, prices, credit, produce subsidies, and other features affect the attractiveness and profitability of different farming systems. Internal factors such as farm size, the available labour force, resources that can be invested, and fixed improvements are other obvious determinants. Finally, personal choice and preferences may influence the system (MacArthur cited in Ruthenberg 1971, p. 282).

Although one must be cautious in grouping farms in an area, however large or small, as practicing a common farming system, this approach has several advantages, provided that both the similarities and the differences between the farms are borne in mind. One advantage is that research can be designed to produce technologies directed to reduce similar constraints on large numbers of similar farms. Similarly, economic and infrastructural interventions can be designed for particular farming systems. In recent years, a large body of literature has grown up around the whole discipline of farming systems research (FSR; see, for example, Zandstra et al. 1981; Shaner et al. 1982).

Although I do not propose to describe details of this methodology here, farming systems researchers described most of the systems summarized in Part II.

Three critical aspects of savanna farming receive particular attention in both this and the following chapters. These are

- First, soil fertility problems — Soil conservation and the maintenance or improvement of soil fertility are crucial to sustainable and productive tropical farming systems.
- Second, risk and uncertainty — Some of the risks facing farmers because of rainfall uncertainty have been described in Chapter 2. Farmers must cope with many other risks, including crop and animal diseases and pests, and economic uncertainties.
- Third, labour productivity — The marked seasonality of savanna farming means that there are peak labour demands for fairly short periods, followed by longer periods with lower demands. Under these conditions, with a relatively inelastic labour supply, farmers find it difficult to increase their labour productivity.

Farmer-Managed Ecosystems

Farms can be considered as ecosystems managed by farmers; thus agriculture is concerned with farmer-managed ecosystems. In his classic work on tropical farming systems, Ruthenberg (1980, p. 2) points out that a farm is both an ecosystem and an independent unit of economic activity, and it is but one system, albeit an important one, among many rural systems. He further suggests that

Farmers use land which originally was part of a natural system, and most ecological systems untouched by man show a "zonal" type of vegetation which is typical for the given natural conditions and which is close to a "steady state" .... Natural systems, however, are unproductive in terms of human objectives. The basic principle of farming is to change the natural system into one which produces more of the goods desired by man. The man-made system is an artificial construction which requires continuous economic inputs obtained from the environment to maintain its output level. Farming thus implies the abolition of an unproductive "steady state" in favour of a man-created, more productive but unstable "state," and much of the farm input (tillage, fertilizers, weeding, etc.) is nothing but an effort to prevent the new state from declining towards an unproductive low-level steady state.

Farming Systems — Intensification

Ruthenberg (1980, p. 358) traced the process of intensification of tropical farming systems, resulting from increasing population pressure on the land, as passing from shifting systems through fallow systems to permanent upland systems, sometimes with perennial crops and irrigation.

Boserup (1965) pointed out that each stage in this process required more labour to produce the same amount of output with a given level of technology, thus there was a direct incentive to practice extensive rather than intensive farming provided that sufficient land was available. Only when land became limiting because of population pressure would farmers intensify their production, and even then they would continue to use techniques adapted to more extensive systems as long as possible, until forced by starvation to adopt more labour-intensive techniques such as manuring and soil conservation, and then, and only then, would they adopt or invent labour-saving technologies such as the plow. She showed that, throughout the world and all through history, some societies had failed to make these adaptations in time, with the result that soil exhaustion and erosion had ruined their land, so that they died out or were conquered by more powerful people, who used them as forced labour to intensify production.

Land Use

In their major contribution to the understanding of African smallholder landuse and farming systems, Allan, with Trapnell and their colleagues, working in the country that is now Zambia, stated their basic concept (Allan 1965, p. 13)

In an underdeveloped country the study of vegetation in relation to soils, climate, and other environmental factors, and the classification of plant associations in accordance with these factors, should provide the most practical single guide to agricultural and forestry potentials.

Allan (1965, p. 5) pointed out that the shifting cultivator worldwide has always needed a detailed knowledge and understanding of the environment to survive.

[The cultivator] can rate the fertility of a piece of land and its suitability for one or other of his crops by the vegetation which covers it, and by the physical characteristics of the soil, and he can assess the "staying power" of a soil, the number of seasons for which it can be cropped with satisfactory results, and the number of seasons for which it must be rested before such results can be obtained again. His indicator of initial fertility is the climax vegetation, and his index of returning fertility is the succession of vegetational phases that follows cultivation. In many cases his knowledge is precise and remarkably complete. He has a vocabulary of hundreds of names of trees, grasses and other plants, and he identifies particular vegetation associations by specific terms. This fund of ecological knowledge is the basis of "shifting cultivation."

Perhaps the major contribution of Allan and his colleagues was in conceptualizing and reducing to quantitative terms some of the complexities of shifting cultivation. These terms included Cultivable Land, the Land-use Factor, the Cultivation Factor, and Critical Population Density. All these terms could be quantified, and together they could give an accurate understanding of the land use under a particular farming system.

Allan found that the Cultivation Factor, which he defined as the area cultivated per head of population, varied very little between four distinct and widely separated farming systems in Zambia. Farmers were growing maize or sorghum in three of these systems and cassava in the fourth as staple foods. The average cultivated area per person was almost the same in these different systems, varying from 0.41 to 0.45 ha. On soils of lower fertility, a larger area of 0.68–0.73 ha had to be cultivated to obtain sufficient food.

Comparing these data with those from other countries, Allan found that in the parts of Kenya and Uganda with two rainy seasons per year, where bananas or other perennial crops were grown with annual crops, average areas under cultivation for subsistence were somewhat lower, at 0.17–0.27 ha/person (some of this land was cropped twice a year with annual crops). In Teso District, Uganda, however, where ox-plows were widely used, and where the second rains were often uncertain, the area was about 0.37 ha/person. In West Africa, the average food-crop area per person in the rain forests of the

Congo, Ghana, and Liberia appeared to be about 0.18 ha, whereas in overpopulated areas of northern Ghana where ox-plows were used, the area varied from 0.27 to 0.72 ha.

The data quoted on other African farming systems later show that although the 45 countries of the African savanna contain an enormous variety of environments and peoples, there are remarkable common features in the farming systems throughout the continent. With the exception of an almost negligible number of larger-scale "commercial" farms, the vast majority of African farmers cultivate 0.2–0.4 ha of subsistence food crops per person. If the full-time work of an adult man or woman is taken as a "man-equivalent" (ME), and the number of MEs often seems to be about half the number of people in a family, the area per ME is about double the above. Thus, the lower figure of 0.2 ha/person, or 0.4 ha/ME, appears to be about the minimum for survival in most grain-producing areas, giving about 200 kg of grain per person in an average year, at a yield of about 1 t/ha, or the equivalent in other crops. Any additional production from the average of 0.4 ha cultivated per person was described as the "normal surplus" by Allan.

Because crop yields were frequently well below 1 t/ha, this "normal surplus" was essential to allow some storage of grain against one or more poor harvests. Where crops are also grown for sale, an additional 0.2–0.4 ha/person may also be cultivated, particularly when simple mechanization such as the ox-plow is used. Then the upper limit seems to be an average of about 0.8 ha/person or 1.6 ha/ME. With an average family size of about 5–6 people, this gives a cultivated area per family of about 1–5 ha (some extended families living together are considerably larger).

Obviously, these overall average figures conceal considerable local variation. In Malawi, for example, with a relatively dense population, the average holding size was 1.16 ha, with a mean population per holding of 4.5 people, giving an average area per person of 0.26 ha. However, 48.6% of the resident population lived on holdings smaller than 1.0 ha, 43.8% on holdings of 1.0–3.0 ha, and only 7.6% on holdings over 3.0 ha (Kydd 1989).

Mean farm size per family appears to vary from about 1 to 10 ha or more, but in areas where population pressure is low and shifting cultivation or its variants are still practiced, farm size may not mean much. Farmers use the land that they need, and other land is usually held communally. Although accurate statistics over wide areas are difficult to obtain, Harrison (1987, p. 23) suggests that 66% of all holdings are smaller than 2 ha and nearly 96% cover less than 10 ha.

Ring Cultivation

Pelissier (1966, p. 474) gives a generalized view of a Senegalese village (Fig. 7), which can also be taken to represent villages or farms throughout the savanna (Ruthenberg 1980, p. 77).

The intensity of cropping decreases in concentric circles or rings from the land immediately around the houses to the outermost fields. The houses in the centre of the village (***1***) are surrounded by a limited area of permanently cultivated "garden" land (***2***) in which a high state of soil fertility is maintained with animal droppings, household refuse, and ashes. Fruit trees provide shade and food and also protect the soil. The next area of land surrounding the village often has reduced fertility because of over-cropping without sufficient addition of materials such as manure to maintain fertility (***3***). The area around this (***4***) may be more fertile because of less intensive use and longer fallows, and the surrounding forest or bush (***5***) may only be used on an intermittent shifting-cultivation basis.

As already outlined, the process of intensification of tropical farming systems under increasing population pressure passes from shifting systems through fallow systems to permanent cultivation systems, sometimes with perennial crops or irrigation (see, for example, Boserup 1965; Ruthenberg 1980). It is of considerable interest that, in Pelissier's diagram, this is the same as the progression from the shifting cultivation area far from the village to the permanently cultivated "garden" land with perennial crops around the houses. (Small irrigated areas may also be cultivated where water is available.) In other words, all the stages of intensification are already present in most villages when land pressure is low, and intensification could be expected to increase as pressure on the land rises, and fallow land becomes limited.

Livestock

Livestock ownership is variable, but a high proportion of farmers keep a few goats or sheep, perhaps averaging about 2–6 animals/farm, and some poultry. A similar average number of cattle are owned by a smaller proportion of farmers, depending on the incidence of trypanosomiasis and other factors. A few farmers keep donkeys, horses, and, in the arid areas, camels. Livestock are not usually closely integrated into the farming system, being mainly grazed on communal grazing lands, often by herdsmen from a different tribe. They may graze stubbles and other crop residues after harvest. Cultivators sometimes provide incentives to herdsmen to herd their cattle on the stubble to manure the land. Farmers under considerable land pressure, such as the Kofyar hill farmers of Nigeria (Netting 1968) or those of the Ukara Island in Lake Victoria (Ruthenberg 1980), have adopted methods of making larger quantities of manure in small enclosures that are then used to manure larger areas. In this way, the "garden" land (Fig. 7) can be enlarged, depending on the number of livestock and the amount of manure that can be made. In both these examples, however, it was striking that when additional fertile land became available to some of the farmers by migration, they immediately expanded their cultivated areas and abandoned most of their intensive practices, as predicted by Boserup (1965).

Ecological Analysis

Although this description paints a relatively simple picture, it is important to stress the complexity and variety of tropical farming systems. The humid zone systems are probably the world's most complex in terms of numbers of crop species involved and their interactions. Also, the 45 countries represented in the African savanna have an enormous diversity of environmental, ecological, and socioeconomic conditions, which lead to a great variety of farming systems.

The relatively simple view of farming systems as farmer-managed ecosystems appears useful for the present purposes, but farms are, of course, parts of many other systems, and they interact in many ways with these systems. These hierarchies of systems have been discussed by Ruthenberg (1980), Norman et al. (1981), and Okigbo (1984) among others.

Fresco (1986) applied ecological systems theory to the study of agricultural production in the Kwango–Kwilu region of Zaire (also see Chapter 8). This approach has the advantage that it provides a theoretical framework for the study of the hierarchy of systems that make up the whole agricultural sector of a region or country.

This hierarchy is summarized in Fig. 8 showing how each level depends on, and interacts with, the levels below and above it. In this example, the crop system and the herd system are at the lowest level (these could be divided into subsystems of individual plants or animals, and subdivided again, even down to cells). Taking the crop system as an example, it can be described in relation to the cropping system of which it is a subsystem (Fig. 9).

All systems involve an arrangement of parts (components or subsystems) that interact according to some process (transform inputs into outputs). The **structure** of a system is defined by the quantitative and qualitative characteristics of the components and the interactions between them. The way in which inputs are processed into outputs determines the **function** of a system. Within the boundaries, all relevant interactions and feedbacks are included, so that all those components that are capable of reacting as a whole to external stimuli form a system; however, boundaries can be difficult to define in complex systems (Fresco 1986, p. 41).

The hierarchy involves successive energy quality transformations. At each step, much of the energy is used in the transformation and only a small amount is transformed into higher quality. A higher level in the hierarchy implies a higher level of energy and a larger scale of time and space. The symbols in Fig. 10 are some of those used by ecologists to indicate what happens to this energy (Odum 1983).

In Fresco's (1986) example, the dominant crop in the Kwango–Kwilu is cassava, so the system consists of cassava as a crop population that transforms solar energy, water, nutrients, and other inputs into biomass. It includes the crop interactions with weeds, insects, pathogens, and predators (Fig. 8).

The next level above the crop system is the cropping system (Fig. 11), which is a land-use system comprising soil, crop, weed, pathogen, and insect subsystems that transforms solar energy, water, nutrients, labour, management, and other inputs into food, feed, fuel, and fibre.

The unit of observation relating to the cropping system is the field, and fields with similar crops, soils, and so forth are considered as belonging to the same cropping system.

The various cropping systems, together with the livestock systems on a farm make up the farming system (Fig. 12). This is defined as a decision-making and land-use unit, consisting of the farm household, cropping, and livestock systems that produces crop and animal products for consumption and sale. Unlike the cropping and livestock systems, the farming system is defined by socioeconomic as well as physical boundaries. The socioeconomic boundaries determine the people who are involved in farming (the farm household) as well as all the resources and inputs, capital, and information managed by the farm household. Its physical boundaries are those of the farm. These boundaries can be difficult to define in shifting cultivation systems.

In some societies, the farm household may consist of several units of the extended family, and other neighbouring households may also be units of the same family, and may share resources, labour, and so on. These more complex units might need different boundaries for the system. Other land-use units such as the village or watershed may form intermediate system levels between the farming system and the regional system.

The regional system (Fig. 13) constitutes a complex, large-scale, land-utilization unit that produces and transforms primary products and involves a sizable service sector, including urban centres. It is the suprasystem of all systems below it. The agricultural sector includes smaller land-use systems, such as the village or drainage basin, that in turn consist of farming systems. The regional system is itself a subsystem of national and supranational systems.

The main components in the regional system are the natural resource base, human resources, agricultural (primary) production, secondary production, and the tertiary (service) sector and their interactions.

The natural resource base, that is, climate, soils, vegetation, and fauna, can be considered as external inputs, as well as components of the regional system. They are components of the system to the extent that they are changed in interaction with other components, but at the same time they provide the environment in which the entire hierarchy of systems is situated. In Fig. 13, the natural resource base is, therefore, partly drawn within the regional system boundary and depicted by the symbol (a circle) for source. Human resources are part of the primary, secondary, and tertiary sectors and do not exist outside these components.

The unit for the regional system may be an administrative unit such as a district or province, but for the purpose of defining boundaries it may be better to select a unit with some natural geographical boundaries, when possible.

Although some areas of mainly traditional agriculture such as the Kwango–Kwilu may be fairly slow to change, it must be emphasized that all ecological systems are always in a process of dynamic change. It seems likely that although many of the interactions may be difficult to quantify, the ecological framework described here could well be used for economic studies both at the farming systems and the higher levels.

Part II — The savanna zones
Chapter 4: The African savanna

The world's savannas lie between the equatorial rainforests and the deserts of the subtropics. Worldwide, they cover about one-quarter of the earth's surface. The term "savanna" is in wide general use to describe landscapes characterized by vegetation types ranging from pure grassland to dense woodland with the presence of a more or less continuous ground layer of grasses beneath or between the trees as the one common denominator. As defined by geographers, the term mainly corresponds to the African part of the geographical entity sometimes described as the Intermediate Tropical or Savanna Zone, which is defined as that part of the tropical world that experiences a dry season of 2.5–7.5 months duration (Harris 1980, p. 3).

However, Phillips (1959) includes semi-arid areas with dry seasons lasting up to 10 months as part of the African savanna, and the term is used in this sense here. Although it is difficult to define the boundaries of the African savanna precisely, it has been estimated that it occupies over 12 million km2 and covers nearly 60% of tropical Africa (Okigbo 1986, p. 95). It includes all or parts of nearly all the 45 countries of tropical Africa. Figure 14 shows the approximate extent of the savanna.

Bioclimatic Zones

For the purposes of this study, in view of the overriding importance of climate, and particularly the length of the growing season and the corresponding dry season in determining the types of natural vegetation and the possibilities for rainfed agriculture in tropical Africa, a classification mainly based on bioclimatic zones as defined by Phillips (1959) is used. This tentative classification also owes much to the work of Chevalier (1900) as further refined by Kowal and Kassam (1978) for West Africa, and to the FAO Agro-Ecological Zones Project (FAO 1978) and related studies (Higgins et al. 1982). The essential feature of the bioclimatic classification is that the natural vegetation closely reflects the integration of rainfall, temperature, and soil. Therefore, areas with the same or very similar types of natural vegetation have similar agricultural potentials.

Obviously temperature differences, usually caused by differences in altitude in the tropics, will have major effects both on the natural vegetation and on the agricultural potential of an area and, for this reason, for the purposes of comparison of farming systems in western and eastern Africa, the Eastern African highlands should be treated as a separate zone. Following Le Houerou and Popov (1981), this area is roughly defined by the 10°C isotherm of the average daily minimum temperature of the coldest month. For example, this gives a lower limit of the highlands of about 1500 m in Ethiopia, 1800 m in Kenya, and 2000 m in Rwanda.

Similarly, some ecologists make a distinction between "tropical" rainfall patterns with a unimodal distribution and "equatorial" patterns with a bimodal distribution (see, for example, Le Houerou and Popov 1981, p. 2). Although there are many variations in rainfall patterns with distance from the equator and other factors, and the criterion "length of dry season" often does not seem to take sufficient account of the fact that there may be two dry seasons and two wet seasons in a year, the natural vegetation does reflect all these variations.

This study does not attempt a detailed ecological classification of Africa, which has been done better by others (see, for example, Higgins et al. 1982), but using some selected case studies sets out to describe broadly some parallels and differences between farming systems in similar bioclimatic zones in different parts of Africa. For simplicity, the desert and subdesert zones with less than 300 mm mean annual rainfall and a dry season longer than 10 months have been excluded. These areas are mainly important for pastoral systems, which are not considered in this study. However, although the study is biased toward the cropping aspects of farming systems, because livestock form an important part of many savanna systems, some consideration is given to their place in the systems. Similarly, large-scale irrigation systems are not included in this study, but small-scale irrigation is included where it is a part of the mainly rainfed farming systems described. Although the humid rainforest zone with mean annual rainfall over 1500 mm and a dry season of less than about 2.5 months is important for rainfed agriculture, it is not part of the savanna as defined here, so it is excluded. The zones are defined in Table 4, and are described in considerably more detail in Chapters 5–8.

Table 4. Bioclimatic zones of the African savanna.

Bioclimatic zone	Equivalent ecological region		Mean annual rainfall (mm)	Length of growing season (days)	Chapter in this study
	West Africa	Eastern and southern Africa			
Arid savanna	Southern Sahelian	Acacia woodland	300–600	60–90	5
Subarid savanna	Sudanian	Southern miombo woodland	600–900	90–140	6
Subhumid savanna	Northern Guinean	Northern miombo woodland	900–1200	140–190	7
Humid savanna	Southern Guinean	Derived savanna	1200–1500	190–230	8

Because African savanna farming systems are closely linked to climatic factors, and particularly rainfall, it is suggested that the farming systems within each of the bioclimatic zones (Fig. 15) described above have more common features than the systems in different zones. For example, the arid savanna zone is characterized by the growing of pearl millet as the dominant cereal crop, except on the heavier soils, where sorghum comes in. In the subarid savanna, sorghum is more important, with some millet and maize. There are also considerable differences between farming systems, even in the same zone, due to differences in rainfall distribution, altitude affecting temperature and evapotranspiration, soils, social factors, and many others. Ideally, the zones should be broken down into more homogeneous subzones that would allow more accurate comparisons to be undertaken and it is to be hoped that someone will undertake this task. However, the results of this preliminary study indicate that there are sufficient similarities between zonal farming systems to make comparisons useful and fruitful, provided that the differences and their probable causes are also borne in mind. In fact, analysis of the differences can also give fruitful results.

Therefore, published information on selected farming systems in each zone in turn is analyzed in later chapters of this study to identify common features and differences from which lessons can be derived on possible improvements to the systems. For example, the description of farming systems in the arid savanna zone starts on the West African coast where this zone is represented in Senegal, and follows the zone eastward, then southwards, and finally westwards as it forms a great arc between the desert and savanna environments of Africa. Each zone is covered in the same way.

Chapter 5: Arid savanna zone

The arid savanna zone (Fig. 16) covers most of northern Senegal from Dakar to just south of the Senegal River, and extends eastward across Africa, including large parts of central Mali, northern Burkina Faso, southern Niger, northeast Nigeria, Chad, Sudan, and Ethiopia. It extends into southern Ethiopia and as a narrow strip through Kenya into Somalia and central Tanzania. It is also widespread in southern Mozambique, Zimbabwe, and eastern and northern Botswana, extending into eastern Zambia and southwest Angola.

The vegetation in this zone consists mainly of *Acacia* spp., with *Acacia senegal* (gum arabic), *Acacia vaddiana*, *Leptadenia pyrotechnica*, *Salvadora* spp., *Grewia* spp., *Acacia seyal* in low areas liable to flooding, and grasses such as *Aristida* and *Chloris* spp., common in the Sahel. In eastern Africa, *Commiphora* spp. are also important. In the Sahel, it appears that nearly all the trees have uses, either for fruit (*Balanites aegyptiaca*, *Phoenix dactylifera*) or for forage (*Acacia* spp.) (Okigbo 1986). Many of the trees and bushes are heavily lopped for feeding livestock in the long dry season, when grazing is short.

Much of this zone has been affected by wind erosion in the past, and dune sands are widespread, particularly in West Africa, although other soils of slightly higher productivity are also represented.

Although the rainfall is marginal and variable, agriculturally this zone is important. In West Africa, a considerable part of it is occupied by cultivators, mainly growing pearl millet often with intercropped cowpeas, and by large herds of domestic livestock. Pearl millet appears to be particularly well adapted to sandy soils, and it will often give some yield even on soils of apparently low fertility. It is the dominant crop in the West African part of this zone, the Sahel. In West Africa, most of the millet varieties are photosensitive, and are adapted to the latitudes where they are grown, so the crop usually matures about the end of the rainy season. Therefore, in the northern part of the zone, earlier maturing varieties (called *souna* in Senegal), which mature in 90 days, are grown whereas in the southern part of the zone, later varieties (*sanyo* in Senegal), maturing in 120 days, fit the longer rainy season. In recent years, a still earlier variety (called *GAM* in Senegal), produced by breeders to mature in 75 days, has become popular (Bilquez 1975).

Senegal

In Senegal, pearl millet is not usually intercropped in the north. Average yields are generally low — around 500 kg/ha. However, research on crop water requirements at Bambey, Senegal, under improved agronomic conditions (heavy fertilizer application, full crop protection, and so forth) showed that the three types of millet would give much higher yields if their average water requirements were met (Table 5).

Table 5. Average crop water requirements and yields of millet varieties of 75-, 90-, and 120-day maturities at Bambey, Senegal.

	Average water requirement in growing season (mm)	1973–77 average grain yield (rounded) (kg/ha)
120-day *sanyo* millet	620	1600–2000
90-day *souna* millet	430	2800–3000
75-day *GAM* millet	350	1700–2300

Source: Dancette (1978).

In 1977, the Bambey rainfall of 374 mm only provided 63% of the *sanyo* millet requirement of 620 mm, and the crop failed, giving a grain yield of only 153 kg/ha. Dancette (1978) has plotted the probability of receiving sufficient rain for a 75-day *GAM* millet in northern Senegal and this shows clearly how risky millet production becomes in the northern part of the arid zone (Fig. 17). Cowpeas of the same maturity length have a slightly higher water requirement, whereas groundnuts have about the same water requirement as millet.

Other crops that are grown in the arid zone include cowpeas, often intercropped, groundnuts, and a limited area of sorghum, mainly on the heavier soils. Groundnuts are particularly important in Senegal, which has relied on their export for the greater part of its foreign exchange earnings for many years. The "groundnut basin" of western Senegal extends from the Louga area in the arid savanna zone about 200 km north of Dakar to the Sine–Saloum region in the subarid zone about the same distance south of Dakar. In a year of good rainfall, Senegal often produces over 1 million t of unshelled groundnuts (Anthony et al. 1979, p. 45). Much research on the crop has been carried out by researchers of the Institute de recherches pour les huiles et oléagineaux (IRHO), now a part of the French Centre de coopération internationale en recherche agronomique pour le développement (CIRAD), and more recently by the Senegalese agricultural research institute (ISRA, Institute sénégalais de recherches agricoles). Like millet, varieties have been bred with maturity lengths adjusted to the varying lengths of the rainy seasons in the country, so that 90-day varieties are grown in the Louga area in the north, 105-day types in the centre, and 120-day types in the south (Dancette 1978).

The farming system that has been developed by the farmers in Senegal's "groundnut basin" appears unique, and has some particularly interesting features. Groundnuts must be planted immediately after the first heavy rains, particularly on the dune sands that are widespread in northern Senegal. Any delay in planting can cause a severe reduction in yield. Therefore, the cultivators prepare the land by a light hoeing during the dry season. Then, as soon as sufficient rains have fallen, virtually the whole crop is planted with single-row planters, usually horse- but sometimes donkey-drawn. It has been suggested that the farmers have adopted these planters, which are not used to the same extent elsewhere in Africa, simply to get the crop planted quickly.

Usually the groundnuts are grown in pure stand, although occasionally a few cowpea seeds may be mixed with the groundnuts. The groundnuts are mainly hand-weeded, or sometimes a light horse- or donkey-drawn weeder may be used. When mature, they are pulled and left to dry for a few days, then the nuts are stripped from the haulms (probably the most laborious job), dried, and stored for sale — the haulms are collected as hay and stored on the roofs of the houses. Groundnuts may be grown repeatedly on the same land, with one or two millet crops after two or three groundnut crops, depending on the cultivators' requirements. Much of the land appears to be continuously cropped.

An interesting aspect of the farming system practiced by the Serer people in the Bambey area is the preservation of the indigenous *Faidherbia* (previously *Acacia*) *albida* and baobab (*Adansonia digitata*) trees. These give a park-like appearance to the country. *Faidherbia albida* is unusual in that it sheds its leaves during the rainy season, and grows new leaves during the dry season, thus crops grown under the trees are not shaded. Because it is a leguminous tree, the leaf fall provides a substantial quantity of nutrients for the crops growing under the trees. Charreau and Vidal (1965) have reported research indicating the importance of *Faidherbia albida* in assisting the maintenance of soil fertility, as well as in providing livestock feed in this system. The Serer also make considerable use of manure collected in the kraals where the livestock are penned at night, mainly using donkey- or horse-drawn carts. The manure is spread in the fields, starting near the homestead, with decreasing quantities reaching the farthest fields

(Pelissier 1966). Some fertilizer (mainly phosphatic) is also applied to the groundnut crop.

Mali

Toulmin (1983) has described the farming systems in Kala village north of Ségou in Mali. This Bambara village in the 400- to 500-mm average annual rainfall belt is in a relatively sparsely populated zone, with only about 7 people/km². In spite of this, it is characterized by growing competition between different groups for access to land and water. Almost the sole crop in this zone is pearl millet. For example, in 1981, the proportion of land under different crops in the village was 71% long-cycle, 120-day (*sanyo*) millet, mainly grown on shifting cultivation land away from the village; 25% short-cycle, 60- to 80-day (*souna*) millet, mainly grown on permanently cultivated and manured land near the village; and 4% other crops, including groundnuts, sorghum, maize, and sauce vegetables.

Although these proportions varied from year to year, the main change was an increase in short-cycle millet at the expense of long-cycle millet. This increase was closely correlated with an increase in the availability of cattle manure, because, unlike long-cycle millet that would give a low yield even on poor soil with little rain but would not yield well on good land, short-cycle millet required manure to yield well, and could fail without it. A farmer's supply of manure could come partly from his own cattle, but because few farmers owned many cattle, additional manure would be obtained from transhumant herdsmen, mainly Fulani or sometimes Maure, who would graze their cattle in the area during the dry season. The key to obtaining manure from these herds was the possession of a well, which enabled the owner to contract with a herder to night-corral his cattle on the owner's millet land in exchange for watering them. Toulmin (1983, p. 13) gives the following description of one villager's acquisition of a well.

Barama had to hire someone to come and dig his well, since he himself was too old and his teenage son too young to get much of the work done. But to get the cash needed to pay the well-digger meant selling most of his already inadequate harvest that year. The family was living from hand-to-mouth for many months, barely managing to feed itself: the son was sent out to work for others during the farming season in exchange for grain, they collected wild fruits in the bush for food, and small quantities of millet were begged and borrowed in Kala and neighbouring villages. It was a very uncertain and gruelling time for all the family and not an experience that many other families might wish to follow.
... He paid a labourer 40 000 Mali francs [about US $50] to dig his well and was able to triple the area of manured land that he cultivated between 1980 and 1981. His total harvest grew from 1900 kg of millet in 1980 to 4700 kg in 1981; of that the short-cycle variety made up 60% in 1980 and 80% in 1981 of the total crop harvested. This increase in output of 2800 kg between 1980 and 1981 was worth 280 000 Mali francs [about US $350 taking 1 kg of millet as worth 100 Mali francs — a fairly low estimate]. Even keeping in mind the possibly exceptional yields of short-cycle millet in 1981, this

calculation does show the substantial benefits that can accrue to a farmer by gaining access to a manure supply.

By 1982, 22 out of the 29 households in the village owned wells, seven of them having two wells each, the second one dug to enable them not only to water their own livestock, but also to engage in manure–water contracts. Households that did not own wells tended to be small and poor and own few livestock and they, therefore, had limited means to invest in a well.

One of the results of population growth has been a migration of farming populations toward the north from areas of higher population pressure in the south. These farmers are looking for sandy soils, which are considered to give higher and more reliable yields of millet, particularly when manured, than the clay soils in the area. Some Fulani herdsmen are also looking for land on which to settle and combine the growing of millet with their herding activities. In Bambara villages, they often appear to be resisted by the Bambara, who wish to keep the land and water resources for themselves, and also fear the loss of the manure contracts if the Fulani acquire their own wells, and possible damage to their crops. For example, in Kala, the only Fulani settled on land are those who are contracted to herd the villagers' cattle.

Plows are widely used both for preparing land and for weeding millet. Farmers who do not possess plows and oxen may hire a team from a neighbour in return for millet or cash, or for weeding part of his millet crop. In recent years, donkey carts have also become widely available, and in some villages these have aided in the breakup of the traditional large extended family units into nuclear families that may become widely dispersed. The donkey carts enable the owners to transport considerable quantities of water to areas that do not have water supplies of their own.

Niger

Much of the southern part of Niger, where the majority of its crops are produced, falls in the arid zone. (Most of the rest of the country is even drier, and is only suitable for extensive livestock production.) The cropping systems are heavily dependent on millet, often with cowpeas intercropped (see for example, Krause et al. 1989). As in northern Senegal, the low and uncertain rainfall causes many crop failures. Farmers cope with these risks in several ways, which include planting several varieties of millet of different maturity lengths depending on the time of arrival of the rains, soil type, and other considerations.

Stewart (1989) has confirmed and quantified these traditional practices. His analysis of 30 years of rainfall records at Niamey indicated that both amount and duration of rainfall in the rainy season are significantly correlated with the date of onset of rainfall as defined for crop production purposes. He divided the 30 years of records into two sets, one with "early onset" seasons (12 years), the other with "late onset" seasons (18 years). The "early onset" seasons were defined as those in which 40 mm of rainfall was stored in the surface soil (considered sufficient for planting) before 15 June, and the "late onset" seasons as those in which the 40 mm was reached after 15 June. He showed that the median total rainfall in the early-onset seasons amounted to 602 mm in a season length of 113 days, whereas the median rainfall in the late-onset seasons was 400 mm in 83 days. Thus the seasons in which the rains started early received 200 mm, or 50%, more rain than the later seasons, while the length of season was extended by 30 days when the rains were early.

Stewart (1989, p. 260) introduced the concept of "response farming" to assist farmers to use these conclusions to improve their traditional farming practices. He pointed out that farmers could modify the varieties, or even crops, that they planted depending on the onset of the rains. Also, although they would plant at close spacing whatever the planting date, they could thin their crops to wider spacings to take account of the lower rainfall when the rains were late. Early planted crops could be more heavily fertilized without undue risk of crop failure than those planted when the rains started later, and other modifications could be made to the farming system.

Stewart (1989) has shown that his response-farming concept can be applied in areas as far afield as Kenya and India, and it is being tested in California and the Virgin Islands in the United States, Nepal, Rwanda, and Yemen. It appears likely that it will be widely applicable in Africa and elsewhere, and it will make an important contribution to the improvement of African farming systems.

Somalia

Somalia is almost entirely arid, with most of the country receiving an average annual rainfall of less than 200 mm. In southern Somalia, a limited area around Baidoa receives an average of 500–600 mm. Usually, the first, more-reliable, rains fall from about April to June, then there is a dry season of about 4–5 months, and the often-unreliable second rains may occur in November–December. The problem in the dryland areas is that neither rainy season is sufficiently reliable in quantity or distribution to produce a crop regularly, so that production is uncertain at the best of times (Hutchinson 1989, p. 201).

There are large areas of dark cracking clays (vertisols) in the southern part of Somalia that appear to have a higher water-holding capacity than the generally sandy soils elsewhere. The Somali cultivators have developed their own system of making a checker-board of small ridges to retain the limited rainfall. Sorghum is grown in the basins that are formed, and in a year of average or above-average rainfall a reasonable crop can be harvested. Where they are well maintained, these basins probably also help to prevent erosion, but the crop-failure rate in seasons of below average rainfall can be high. The cultivators usually try to plant a second crop in the second rains, but the yields are usually low and the crop may fail as often as once in every 3 years. In 1986, for example, much of this area did not receive any rain at all in the second rainy season, so that all crops failed and severe hardship was caused to many people in early 1987.

One way in which the cultivators have attempted to respond to this uncertainty is by ratooning their first-rains sorghum crop in the hope that the regrowth may produce some grain in the second rains. Yields obtained by this method appear to be generally low, and it may also contribute to the carry over of stemborers that often cause severe damage to the crop. Population pressure on the better soils is increasing, and deficiencies of phosphate are widespread. Some of these soils have a high phosphate-fixation capacity, so that heavy and uneconomic broadcast applications were sometimes found to be necessary to increase yields. Recently, it has been found that good responses can be obtained from small phosphate applications placed near the seed at planting (University of Wyoming 1990).

Few other crops except sorghum are grown, although some cowpeas may be planted in pure stand or intercropped, and a little maize, groundnuts, watermelon, sesame, and tomato are sometimes grown in low-lying areas. Attempts have been made to introduce cotton with some success in limited areas.

As elsewhere in the arid and subarid zones, the most widespread agricultural activity in Somalia is livestock keeping. Many of these stock belong to nomadic or transhumant herdsmen, who often move to and from the Ogaden area of Ethiopia or other areas with their herds, depending on the availability of grazing and water supplies.

Although some Somalis have cultivated sorghum for many years, many relied mainly on their livestock for their food supplies. In recent years, in suitable growing areas, an increasing number have taken to growing some sorghum while maintaining their livestock, which are taken to the traditional seasonal grazing area by some of the young men of the family. Animal traction is used by some farmers, but is not widespread. Manure is not generally used.

The two important rivers in the south of the country, the Shebelle and the Juba, are being increasingly used for irrigation, particularly of maize and sorghum. There are also limited areas of plantation crops, principally bananas for export, sugar cane, and some citrus and other crops.

Tanzania

In Tanzania, a large area extending from the Masai steppe south of Arusha through Dodoma and central Tanzania to Iringa comes in the arid zone.

A soil and water management project of Sokoine University (supported by the International Development Research Centre, IDRC) working in four villages near Dodoma, central Tanzania, found that the main crops produced were maize, sorghum, pearl millet, and groundnuts. Minor crops were bambara groundnuts and sesame. The soils were predominantly sandy clay loams with heavier soils in the bottom lands. The farmers identified low and uncertain rainfall and declining soil fertility as two of their main farming problems — these led to almost total crop failure in some seasons. For example, in 1989/90, the average grain production per person in Chamwino village was recorded as only 91 kg, probably below the margin for survival. This project expects to obtain considerable further information on the farming systems in the area and is testing a number of simple water-harvesting methods to see if they are useful to the farmers (Sokoine University 1993).

Zimbabwe

Ndowoyo is an area in the dry southeast of Zimbabwe with an average annual rainfall of 570 mm. In the Zimbabwe agroecological classification, it is in Natural Region V, which is classified as unsuited for arable cropping. Despite this, the main farming activity is rainfed cropping combined with cattle herding, with sorghum as the major traditional crop. Soils are mainly vertisols.

Nyamudeza et al. (1993) have described the difficulties of crop production in this area. Midseason droughts occurred frequently and it was found that, on average, sorghum and cotton would produce one good crop, three mediocre, and one failure in 5 years. Maize would produce one good crop, two mediocre, and two failures.

Trials of tied furrows (made by ridging the land and making crossridges every 1–2 m, then planting in the furrows) on the Chisumbanye Experimental Station were promising, and a program of on-farm testing was started. At first, farmers were doubtful as they feared waterlogging and the high cost of ridging. Over eight seasons, the yield advantage of sowing in tied furrows over sowing on the flat was 25% for sorghum, 46% for maize, and 32% for cotton. Yield levels varied widely from season to season but sowing in furrows tended to produce heavier yields in all seasons. The lowest yield increase, less than 5%, was in the one season of good rainfall.

Without exception, farmers expressed their willingness to try the new system on their farms, but most did not have sufficient resources to prepare the furrows. Most farmers preferred tractor ridging but did not have the money to pay for it. Oxen were usually too weak after the frequent droughts to ridge the land, except for those farmers who lived near an irrigated estate where they could cut and carry grass from the canal banks to feed their oxen.

By 1991, however, it was estimated that over 150 farmers had some of their crops planted in tied furrows, and the increased yields were profitable even after paying out an extra ZW $50/ha (Zimbabwe dollar) for hiring a tractor and ridger, and paying for the labour for crossties.

Synthesis

The arid savanna zone, which is on the edge of the Sahara desert in west Africa and the Kalahari desert in southwest Africa and is characterized by low rainfall (300–600 mm/year), a short rainy season (2–3 months), and frequent droughts, is most at risk of crop failures. Yet farmers in Senegal have adapted to the harsh conditions by developing their own early maturing millet varieties, and by adopting horse-drawn groundnut planters to plant the crop at the optimum time. The Serer people of Senegal have traditionally protected the leguminous *Faidherbia albida* trees, which shed their leaves in the wet season thus manuring the soil, to provide feed for livestock in the dry season. They also spread manure on their fields using donkey- or horse-drawn carts. Researchers have also made major contributions by breeding earlier-maturing millet and groundnut varieties.

In Mali, those Bambara people who do not own many cattle have developed a system of contracting with Fulani or Maure herdsmen to night-corral their cattle on the millet land in the dry season to manure it. This is done in exchange for watering the cattle from wells. It seems likely that similar practices are widespread across the arid and subarid zones, as they are also found in Nigeria and other areas.

In Somalia, farmers have developed their own methods of planting sorghum on a chequer-board of small ridges on the vertisols to retain rainwater. Researchers have recently found that small applications of phosphate placed near the seed can give considerably increased yields.

In southern Zimbabwe, researchers found that planting on vertisols on tied furrows, a little like the Somali system, gave considerable yield increases of maize, sorghum, and cotton. Over 150 farmers had adopted this system by 1991.

It is clear from this that both researchers and farmers have developed similar technologies on comparable soils in the arid zone throughout Africa, and both would probably benefit from comparing and testing these and other technologies throughout the zone.

Chapter 6: Subarid savanna zone

The subarid savanna zone (Fig. 18) extends from Dakar to include much of central Senegal, central Mali, southern Burkina Faso and Niger, most of northern Nigeria, and central Chad. In Sudan, it widens to include a large area of the central rainlands, and some of the irrigation schemes on the Blue Nile. A large area in the north and part of the Rift Valley south of Addis Ababa in Ethiopia, the Karamoja District of northeast Uganda, together with a limited area in the Kenyan Rift Valley and to the east of Nairobi, and part of central Tanzania are included. Most of western Zimbabwe and part of southern Zambia and southern Angola are also in this zone.

The predominant upland soils in this zone are alfisols, but there is considerable local variation, including dune sands in parts of West Africa, vertisols around Lake Chad and in Ethiopia, Somalia, and the Sudan, and oxisols and entisols in southern Africa (see Fig. 5).

The vegetation in much of this zone consists of mixed combretaceous and *Acacia* tree savanna, with *Faidherbia albida* and *Hyphaene thebiaca* as indicator species. These species, as well as *Parkia* spp., are protected and used for browse. Mango is planted where ground water is not too deep. Grasses include *Cenchrus ciliaris*, *C. biflorus*, *Eragrostis tremula*, and *Pennisetum pedicillatum* (Okigbo 1986, p. 98).

This is an important zone agriculturally, with heavy concentrations of population throughout much of both western and eastern Africa. In this zone, the millet system described in Chapter 5 is found on the lighter soils, but sorghum is the dominant crop on the heavier soils, with maize becoming increasingly important, particularly in eastern and southern Africa. Cowpeas, groundnuts, and cotton are also grown. Many cultivators own cattle, sheep, goats, donkeys, and horses.

Senegal

Considerable research has been carried out on improved farming systems in the "Unites experimentale" in the Sine–Saloum area in Senegal. Farmers in this area appear to have been some of the first in West Africa to have adopted animal traction, in the form of ox-plows. Their use is now widespread in the southern part of Senegal, together with the horse- or donkey-planters described under the arid zone, which are particularly used for groundnut planting. Ruthenberg (1980, p. 150) comments:

The commercialization of the area began about 1850, and it has accelerated in the last forty years. The traditional fallow system has been replaced by a permanent cropping system, with groundnuts as the dominating crop, which is unsurpassed in the area in terms of returns per hectare and per hour of work. The guiding principle of land use is a simple one. There have to be sufficient cereals for food (about 0.25 ha per person yielding 200 kg at a yield expectation of 0.8 t/ha). 90-day pearl millet supplies early food, and 130-day sorghum supplies food later in the season. The rest is planted with groundnuts. Some rice is grown in valley bottoms. Farmers now tend to replace millet with early-maturing maize, which yields much more, produces green maize as food even earlier than millet, requires less threshing work, and no bird-scaring, and is simpler to store.

The Wolof people of this area usually live in fairly large villages, and family sizes are still quite large. Up to about 2 ha/person may be cultivated. As described for the "ring culture" system, the land around the village is usually manured and used for maize and millet growing, while the land further from the village is used for groundnuts, often rotated with millet or sorghum, and sometimes cotton. Some artificial fertilizers are used, but because most of the land is permanently cropped, there appears to be a steady decline in soil fertility.

Most farmers own some cattle in addition to goats, sheep, donkeys, chickens, and perhaps a horse. The livestock are fed on communal grazing land and crop residues, and browse, including *Faidherbia albida*, is also fed in the dry season. The livestock are often herded by hired Fulani herdsmen, and are used for up to about 100 days work in the fields per year. Horse-drawn passenger vehicles, which are also used as taxis, are common in this area.

Burkina Faso

In Burkina Faso, the zone includes the Mossi Plateau area around Ouagadougou, where major agricultural problems are developing. The Mossi Plateau is relatively densely populated, with about 60% of the population of the country and up to 40 people/km², and the soils, which are mainly fine sandy loams, are often shallow over underlying ironstone gravel or plinthite. Heavy population pressure, overcultivation, and erosion have led to serious losses of topsoil and, in several areas, widespread denudation and exposure of the subsoil in the form of gravel or plinthite (de Wilde 1967, p. 370). It appears unlikely that some of these areas will ever carry a crop again. In 1984, an estimated 700 000 Burkinabes lived outside the country, constituting roughly 25% of the labour force. There seems little question that this large-scale labour movement southward, mainly to the Cote d'Ivoire, was primarily a response to the difficulty of making a living at home.

Matlon (1984), a regional economist with the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), carried out on-farm tests on a stratified random sample of farms in two villages in each of three distinct agroecological zones. One of these pairs of villages, with about 750-mm annual rainfall, comes into the subarid zone. The stratification of the 25–30 farmers participating in each village was defined by the ownership or nonownership of animal-powered equipment for cultivation. ICRISAT's objectives were to test "improved" technologies (mainly high-yielding varieties) produced on a local research station under farmers' conditions to determine their technical adaptation and acceptance or rejection by the farmers. As in Senegal, sorghum is the dominant crop in this area, with millet important on the lighter soils. Under normal farmer management, the local sorghum varieties gave average yields of 189 kg/ha on the shallow plateau soils, and about 600 kg/ha on the slightly deeper soils further down the slope or toposequence. Some tests were carried out in 1981 comparing the local and some improved sorghum varieties with the local recommended practices of plowing before planting and 100 kg fertilizer (14 kg/ha N, 23 P_2O_5, 15 K_2O).

The results (summarized in Table 6) suggest that there was little yield advantage for the farmers in growing the improved varieties using their normal management on the plateau and upper or mid slopes, and only a small advantage with E35-1 on the lower slope. The extremely low yields (between 144 and 318 kg/ha) on the plateau soils, which are the most widespread, with all varieties under farmer management, and with all except the hybrid CSH5 under improved management, are striking. It would be most interesting to know how low the yield must fall before the farmer decides the crop is not worth growing. With improved management (plowing and fertilizing), CSH5 gave a higher yield on the plateau, and both E35-1 and CSH5 gave small yield increases on the mid and lower slopes. Interestingly, some farmers decided to use farmyard manure as well as fertilizers in the tests, and these farmers achieved gross margins with the improved variety E35-1 nearly double those with the local variety.

Table 6. Mean grain yields (kg/ha) of local and improved sorghums by position down the toposequence at two levels of management, Nakomtenga and Nabitenga villages, Burkina Faso, 1981.

	Farmer management				Improved management			
	E35-1	38-3	CSH5	Local	E35-1	38-3	CSH5	Local
Plateau	–	318	144	189	–	185	813	273

Upper slope Midslope Lower slope	268 685 810	305 311 516	773 537 602	605 626 606	966 1405 1389	1048 915 1106	1256 1369 1202	1101 1197 1150
Source: Matlon (1984, table 3).								

With fewer inputs, the local variety often gave a higher gross margin than the improved one. Matlon (1984, p. 108) summarized part of an economic analysis of these results as follows.

The results ... clearly demonstrated the high risks associated with fertilizer use in semi-arid conditions under farmers' management. Thus, even with mean financial returns of 77% and 42% in the high- and middle-rainfall zones, the percentages of fields where incremental yields did not cover subsidized fertilizer costs were 44 and 70 for the local varieties. Costing fertilizer at its unsubsidized price found average negative returns for all cases except improved sorghum varieties in the high-rainfall zone and under lowland conditions in the lowest-rainfall zone. An important question left unanswered was whether the recommended dose (100 kg/ha) of the available NPK fertilizer was the optimum dose. A farmers' test was subsequently designed to address this question.
Although further analysis of the large quantities of data collected in these case studies should yield a considerable amount of interesting information, and some highly detailed studies of this type are obviously desirable, it is difficult to determine to what extent the results can be extrapolated to other areas of Burkina Faso in the same bioclimatic zone.

Lang and Cantrell (1984) have described some of the work of the Purdue Farming Systems Unit in Burkina Faso. Their principal findings were the following.

In two villages on the central plateau, and in half of the sample villages on the edge of the plateau, the farmers are clearly oriented toward subsistence. They claim to ignore price in cropping and in deciding when to sell their crops. Their sales are strictly residual, prompted only by "urgent need," regardless of the market price. If, as harvest approaches, their stocks are adequate, they sell grain to purchase small ruminants, which are kept for sale during lean years. The data documented the farmers' reliance on livestock sales as a principal source of revenue to purchase grain. Thus, the farmers are not, by plan, part of the cash economy.
Although the principal grain crop in all three villages is millet, farmers would like to plant more sorghum because sorghum stores twice as long (3–4 years) as millet (1–2 years) and, during good years, yields more than millet. They plant less than desired quantities because the variability in yield of sorghum and, therefore, production risks are much higher than those associated with millet.
Labour, as has frequently been observed in other studies, is often a binding constraint during the first weeding but is slightly more available during the second weeding.
Millet plantings are highly and consistently correlated with the number of active labourers/household. Sorghum plantings are confined to land that is more fertile or has better water retention.

Use of draft animals is profitable in the land-abundant zone because of intensification effects, and on the central plateau where extensification is possible. On the plateau, no intensification effects were detected.
In two villages, the farmer-managed millet trials showed statistically significant ($P < 0.05$) yield responses to phosphate in the seed pocket and to tied ridges. The most promising treatment was a combination of the two techniques. For one village, average yield increases easily covered cash costs and provided returns to labour of about 28 CFA/work hour [about US $0.10].
Roth and Sanders (1984) used a modeling technique to examine the effect of animal traction, with and without tied ridging, and the use of inorganic fertilizers on farm production and profitability on the Mossi Plateau and in the eastern region of Burkina Faso. On the Mossi Plateau, farmers mainly used donkeys for interrow weeding sorghum and millet as they preferred to prepare the land for planting by shallow hoe cultivation during the dry season so as to plant right at the beginning of the rains. The small areas of land planted to maize and groundnuts are often plowed. In the Eastern Region, animal traction is used primarily for land preparation as oxen are the main power source, and little weeding is done with animals. Farm-level studies showed that animal traction reduced labour requirements by 11–43% in the two regions, but because the households using animal traction were mainly the larger households, there was little increase in productivity per worker. Tied ridging plus a modest application of inorganic fertilizer almost doubled the yields of sorghum in both regions, but income per worker only increased by 11% (donkey) and 24% (oxen), respectively. There was little effect on pearl millet yields. It appears that the benefits of manure from the animals may be more important than their use for traction, but the production and use of manure needs more study.

Nigeria

A considerable amount of research on farming systems has been carried out by many researchers in northern Nigeria (see, for example, Jones and Wild 1975; Norman et al. 1976; Kowal and Kassam 1978; Ouedraogo et al. 1982).

A particularly important feature for the purposes of the present study, and indeed for agricultural development throughout Africa, is the sustained intensification of smallholder rainfed agriculture that has been achieved in some areas of high population density. For example, Grove (1961, p. 125) has described the land-use situation in a heavily populated area.

Northern Katsina: Dense settlement, land impoverishment and emigration — Towards the central districts of the Kano region population densities increase, and all the inner agricultural zones surrounding villages have a greater radius. The proportion of village lands under yearly cultivation is larger, and at some critical figure of population density the outermost zone of bush fallow farming is eliminated from the land-use pattern as a continuous feature. This critical figure varies with the soil conditions but it is probably of the order of 150 or 200 to the square mile [58 to 77 people/km^2]. Where population densities are lower than this, land use is commonly unspecialized; land is not used for different purposes according to its inherent capabilities, but any particular patch may be under woodland at one time, rough-grazing at another, cropped for a few years and then abandoned. In more heavily settled areas, there is a closer relation of the land-use pattern to soil conditions.

Hill (1972, p. 13) made a detailed classic study of the village of Batagarawa, which is 10 km south of Katsina. She pointed out that, unlike Bindawa village, which was more densely populated at the time of her work in 1967, population densities in this area were not so high that bush farms (farms that included some land under bush-fallow) had been entirely eliminated from the agricultural landscape. Also at that time much of the bush-land within 3–4 km of the village was still uncultivated, apparently because it was surplus to the farmers' requirements.

The 1967 population was made up of 386 men, 399 women, and 610 children, 1395 in all, of whom 1103 lived in the walled village (Hausa: *gari*) and 292 in dispersed farm houses; 1226 people (88%) made up 171 farming-units each headed by a farmer, and the remaining 69 people made up the households of the four ruling families (Hausa: *masusarauta*). Half the population was in farming units of 6–10 people, but as many as half the "heads of farming units" were single-handed farmers. Four farming units were much larger, with 20–30 members each. The main crops were sorghum, pearl millet (both early and late varieties), cowpeas, and groundnuts. Subsidiary crops included tobacco, sweet potato, cassava, local vegetables, rice, henna, hemp, and various tree fruits and seeds (particularly locust beans, *Parkia clappertoniana*).

Hill (1972, p. 20) makes the important observation that the manured farms around the village are continuously cultivated, normally without any fallow period, even though the farmers have access to bush farms and uncultivated land within a short distance. She describes the manuring practices.

Despite the fact that land is plentiful, individual farmers prefer to concentrate their farming in the manured zone, and some of the most successful of all farmers do not trouble to cultivate any bush-farms. The main types of manure are compound sweepings, including the droppings of small livestock (sheep, goats and donkeys), which are of fundamental importance in this economy, and cattle dung which is partly provided by cattle owned (or cared for) by Batagarawa people ..., partly by non-resident Fulani pastoralists who are paid for bringing their cattle to graze on the farms after harvest. Imported chemical fertilizers are very popular, and increasingly applied, but are as yet of little importance relative to natural manures, including latrine manure.

If Hill's conclusion is correct, that the Hausa have developed a farming system that maintains soil fertility under continuous cropping, the implications could be important for many areas elsewhere in Africa with similar climate and soils, provided that sales off the farms, and consequent nutrient losses, are not too heavy.

Norman et al. (1981, p. 52) point out that the traditional cropping system in many parts of the West African savanna involves the permanent cultivation of some fields, usually near the house compound, and the maintenance of soil fertility through manuring. Fields further away are cultivated for a few years, after which soil fertility is restored primarily through fallowing. The fields near the compound are usually common fields used for food crops, whereas the fields further away that are cultivated intermittently may be used more for cash crops. They describe recent changes in the system.

Increasing land shortages concomitant with rising population densities are resulting in an increase in the production of permanently cultivated fields, and the remaining fields are being left fallow for progressively shorter periods.... Traditionally livestock herders and sedentary crop farmers have had some symbiotic relationships in which manure for fields is an important element.... Although with the problems of continuing this complementary relationship in the face of progressive decreases in grazing land, there is also the question of whether such a relationship can provide the increasing amounts of organic fertilizer required to maintain soil fertility. It has been noted that, apart from a few exceptional areas such as that around Kano in northern Nigeria ..., the decrease in yields has not been forestalled. This problem has been of particular concern in the francophone countries, where the introduction of animal traction has been seen as a means of alleviating such problems.
In general there appears to have been an assumption on the part of researchers responsible for developing improved technology that all fields are viewed in the same way by farmers. The above observations concerning the "ring cultivation" system [see Fig. 7] appear to repudiate this assumption, although the implications for development of relevant technology are unclear.
One would expect, for example, that the fertility would be an important issue with reference to fields close to residential areas, which are also likely to have increased *Striga* [a parasitic weed of cereals] infestation due to the continuous cropping of cereal crops. On the other hand, labour efficiency is likely to be more important in more remote fields, but mechanization problems are likely to be greater there because fields often have not been adequately destumped.
Various methods of using livestock to increase manure supplies on the permanently cultivated land near the compound were traditionally practiced. Where the livestock were owned and managed by the cultivator, the night *boma* (corral) was sometimes moved from time to time, and the land that was thus manured was cultivated (Ruthenberg 1971, p. 66). Where the cattle were owned or managed by itinerant herdsmen, usually Fulani, the cultivator might provide crop residues, water, or even money to encourage them to herd their cattle for varying periods in the dry season on the cultivated land, usually near the homestead.

Mixed cropping is an important practice throughout the savanna, but this has sometimes been criticized as possibly reducing production and labour efficiency. Labour requirements and yields for sole and mixed crops at Sokoto in northern Nigeria have been measured by Norman et al. (1979). Although yield per hectare of each crop was reduced when the crops were mixed (Table 7), the net value of the production and the net return to labour from mixed cropping was increased about 25% in this study. In addition, the farmer's food security would be improved in case of loss of one of the crops.

Table 7. Comparison of sole and mixed crops on rainfed land (annual average rainfall, 752 mm), Sokoto, Northern Nigeria.

	Sole crops	Mixed crops
Labour (person-hours/ha)		
Annual	425.8	485.6
Labour peak period	232.5	238.0
Yield (kg/ha)		
Millet	736	686
Sorghum	652	122
Groundnut	429	188
Cowpea	–	56
Source: Norman et al. (1979).		

Cameroon and Chad

Burnham (1980, p. 150) has described the farming systems of the sedentary Fulani, Guiziga, Kera, Masa, and Tupuri peoples of northern Cameroon and Chad. Here, sorghum is the staple crop and at least three main types are grown; early ripening "wet-season red" sorghums, later ripening "wet-season white" sorghums, and "dry-season transplanted" or *muskwari* sorghums that are sown in seedbeds toward the end of the wet season and transplanted on the seasonally flooded clayey soils (mainly vertisols) of the Lake Chad basin as the flood recedes. These soils retain sufficient moisture into the dry season for a successful crop. Although the cultivation techniques are more labour-intensive than those for wet-season sorghum, they come later in the season so they do not compete for labour at the peak period for the wet-season sorghums.

A few people in this area may also grow early finger millet to obtain an early harvest after the "hungry gap."

Sudan

Further east, in the Sudan, the subarid zone is characterized by large areas of sorghum grown on the dark cracking clays (vertisols) of the central rainlands (Tothill 1948). In recent years, an important development in this area, particularly in the Gedaref region, has been the allocation of large blocks of land (averaging 400 ha) to certain wealthy individuals who use tractors to cultivate the land mainly for sorghum growing (Bunting, H.H., Reading University, Berks., UK, 1987, personal communication). These individuals are often traders or businessmen who live in cities and employ a manager to crop the land. In this way, some companies have obtained the use of very large tracts of land. By 1968, over 500 000 ha was being cultivated in this way.

Because there does not appear to be any provision for rotational cropping or the maintenance of soil fertility, most of this land is cropped continuously for a few years until it is exhausted. The tractors may then be moved to a new site, sometimes as much as 90 km away, on a shifting-cultivation basis. Under this extractive system, because the tractors are only used for discing and planting the crop, roads and water supplies are often lacking and labour is scarce, weeds such as *Striga* may become widespread, and serious erosion has occurred in areas where slopes, although gentle, are long (Agabawi 1970).

There appear to have been hopes among some of the Arab countries around the Persian Gulf that the Sudan could become the breadbasket of the Middle East, but these hopes have not materialized yet.

Salah El-Din El-Shazali (1980) has described a more typical Sudanese farming system at the village of Kukur, which is between the Blue Nile and the White Nile south of Khartoum, in an area on the clay plains with an average annual rainfall of about 900 mm. The average cultivated area per family was estimated as 3.15 ha in addition to a small garden plot around the house compound. Because land was not limiting at that time, farmers would partly clear an area (*bildad*) of trees that would be burned. This would be divided into two halves, and sorghum and sesame would be alternated on each half until the *bildad* was exhausted, when it would be left to rest for up to 10 years, and new land would be cleared. Although sorghum yielded better than sesame, sesame fetched a higher price and the rotation helped to maintain fertility and reduce weed buildup. Farm size was limited by labour availability because, although most farmers owned some cattle and goats, ox plows were apparently not used, so all cultivation was by hand hoe. Tractors were available for hire but farmers could not afford to hire them. Groups of men would work together on a reciprocal basis on each others' sorghum plots for food and beer. Women also worked in similar groups. Many young men would go away to work on one of the large mechanized farms to get money for marriage and so forth.

East Africa

The limited areas of Kenya, northeast Uganda, and the large part of Tanzania that come into the subarid zone are mainly characterized by having two rainy seasons, or in southern Tanzania by a bimodal rainfall becoming more unimodal in the extreme south. Virtually all these areas are situated at about 800–1200 m altitude on the East African plateau. Therefore, the lower temperatures, and in some localities, higher humidity, reduce the evapotranspiration rates so that the rainfall is more effective than at lower altitudes, provided that runoff is controlled. However, the problems of two rainy seasons, neither of which may be consistently sufficient to produce a satisfactory crop, are severe.

Uganda

In the Karamoja district of northeast Uganda, as in the Sudan and Somalia, the main crop grown is sorghum, and the soil type in much of the cropped area is a black cracking clay (vertisol). Ox plows are widely used for land preparation, as many as a dozen teams often working on contiguous plots at the beginning of the first rains. The sorghum is planted, weeded, and harvested by hand, and the crop is stored on-the-head in traditional granaries. A little maize and cowpeas may be planted on the lower slopes of valleys where groundwater may be available. Usually, little attempt is made to grow crops in the second rains, which are short and unreliable in this area as in Somalia.

Traditionally, like the Somalis, the Masai, and other pastoral peoples, the Karamojong were transhumant pastoralists. As elsewhere, the increasing human population has necessitated keeping a number of animals that exceeds the carrying capacity of the pasture under the unrestricted grazing system. This led to severe denudation of the cover of palatable grasses and other vegetation, leaving bare soil that became seriously eroded. Inedible xerophytic plants, such as *Sansevieria* sp. and thorn-bush, spread into some of these areas further limiting the potential grazing land.

One of the valuable series of catchment research projects started by the now-defunct East African Agricultural and Forestry Research Organisation (EAAFRO) in the 1950s was established at Atumatak near Moroto, which has a mean annual rainfall of 753 mm (Pereira et al. 1962; Blackie et al. 1979). The project collected useful data on land and water management in that area, and showed clearly that the livestock-carrying capacity of the land could be increased by some simple grazing-management practices that maintained a cover of indigenous grasses on the land. This ground cover had the effect of reducing the runoff, which was found to amount to about 14% on overgrazed bare soil, to about 7% or less under improved grazing management (Blackie et al. 1979, p. 185).

Tanzania

De Wilde (1967, pp. 415–450), has described the agricultural situation in Sukumaland, to the south of Lake Victoria. In 1965, about 1.1 million Sukuma occupied an area of about 44 000 km². They possessed some 3.5 million cattle and 3 million sheep and goats — these numbers may have doubled by 1995. The soils range from light, free-draining, and erodible hill sands to heavy *mbuga* soils (vertisols) in the valley bottoms in a gently rolling topography. Traditionally, the Sukuma practiced shifting cultivation of pearl millet and sorghum, but in recent years maize has tended to become the dominant cereal. Cassava, groundnuts, sweet potato, and legumes are also grown. Cotton is the most important cash crop, and some rice and sisal are also produced, mainly for sale.

Ruthenberg (1980, p. 97) indicates that about 1.25 ha of cotton; 1.25 ha of sorghum, millet, and maize (often mixed); 0.60 ha of rice; and 0.70 ha of cassava, giving an average crop area of 3.80 ha/farm, were grown on farms averaging 8.5 people and 6.90 ha in 1976. This gives 0.33 ha/person of food crops and 0.68 ha/person of cotton, or a total cropped area per person of just over 1 ha. With a labour force of 3.7 ME/farm, this is equivalent to 1.86 ha/ME. An average of 2 head of cattle and 10 sheep and goats were also kept. At that time, most people were living in *ujamaa* villages (Tanzanian collective villages), and had to spend an average of 1.5 hours/day walking to and from their cultivated plots.

Upland crops are planted on ridges, 50 cm high and 1.3–1.5 m apart, made with hand hoes. At the beginning of each cropping season, the weeds and crop residues are removed from these ridges and put into the furrows. The ridges are then split by hand so the organic matter is concentrated in the centre of the ridge and the weeds are smothered. The new season's crops are then planted on the new ridges, which assist in reducing erosion. Tie-ridging was tried, but is not generally practiced. Ox plowing has spread rapidly since the 1950s particularly in the drier areas, and especially for cotton growing on the flat. This roughly doubled the area cultivated per worker.

With the growth of population, land pressure has increased and it appears that some 70–80% of the potentially arable land is cropped each year. Cotton and cereal yields are gradually declining, and the area of cassava is increasing as soil fertility decreases. Manure is left in the *bomas*, and is not normally applied to the fields. Occasionally a *boma* may be moved and the site may be used for vegetables or other garden crops. This system is very demanding for labour before and during the cropping season, requiring about 2226 person-hours/farm, roughly half for cultivation and half for herding. The gross margin per hectare or per worker was about US $187 in 1976.

Zambia

Anthony et al. (1979, p. 179) have analyzed the farming systems in Mazabuka district, near the Zimbabwe border, where there is a mean rainfall of about 840 mm/year in one season. They comment as follows.

Mazabuka farmers have worked beside European farmers for seventy years, and many of them have at one time or another worked for European farmers. The first Europeans to farm in Zambia relied on draft oxen, and Tonga farmers learned the practice from them. Later, when the Europeans adopted tractors and trucks, African farmers bought their used ox-drawn equipment and sometimes their trained oxen, but it was not long before some of them owned tractors and light delivery vans, too. European farmers constituted a large enough market for purchased inputs to support agricultural supply firms, which supplied black and white farmers alike with seeds, chemicals, and farm tools.

In 1967 the Mazabuka District presented a picture of active and comparatively rapid agricultural change that had its roots in the early century. An increased demand for maize, which coincided with the availability of ox-drawn implements, made for an increased acreage of the maize crop. During this early period a familiar pattern of agricultural development emerged. Increased agricultural output was achieved by the expansion of acreage and yields remained low.

Alienation of land, natural population increase, and a tendency to move to fertile soils along the rail line and near markets led to localized high population densities. At the same time there was a rapid buildup of Tonga cattle herds, which resulted in overstocking in some areas. This led to a government soil conservation program. The major works put in, and particularly the provision of cattle watering points, benefitted all farmers.

The Tonga are a strongly individualistic people and there are no strong barriers to inhibit personal initiative. Taking the opportunity presented by the availability of a market for maize, a small class of comparatively large farmers had emerged by the late 1940s, and some were already selling several hundred bags of maize. By 1950 a few had gross incomes of £1000 [US $2000] or more per annum. Most of this came from the sale of maize, but poultry, cattle, and pigs provided important secondary sources of income. A few farmers had invested in trucks and one or two in tractors, with which they did custom ploughing for their neighbours. With the incomes obtained from farming, capital investment in farms continued. This took the form of better housing, wells, the occasional windmill, fencing, implements, and machinery.

In the 1960s, farmers were introduced to major technical innovations, hybrid maize seed, and a new cash crop, cotton. With the use of hybrid varieties and fertilizer, yields of thirty to forty bags per acre [equivalent to 6–8 t/ha] became obtainable. The two inputs, double hybrid seed and fertilizer, cost about £9 per acre [US $45/ha] at the recommended rate. However, the survey showed that substantial and increasing numbers of Tonga were purchasing both inputs, and that individual farmers were getting yields of over twenty bags per acre [4.5 t/ha]. The wider use of these innovations was stimulated by the provision of substantial credit and facilities for marketing and the purchase of inputs. Farmers were slower to adopt cotton growing, as they were unsure whether the crop provided a better return to investment than maize. Anthony et al. (1979, p. 181) continue:

Agricultural change among the Plateau Tonga over the last sixty years has been impressive, whether measured against the situation existing at the beginning of the century or against the experiences of other African savanna areas, and in recent years the contribution made by agricultural scientists has been of key importance. The Tonga farmer has responded readily to economic incentive. Future development in the area will depend on the availability of markets for Tonga produce. At present the district is essentially a one-crop area, but sales of cattle and milk provide substantial additional income.

A controversial aspect of development in the area is the extent to which assistance should be provided for tractor mechanization on small- and medium-scale farms. A minority of Tonga farms in Mazabuka District are large enough for the economic use of tractors, and there are others that would benefit from the use of seasonal tractor hire for land preparation. However, this is a situation that is best left to the enterprise of the Tonga themselves. Past development suggests that, as the need arises, the wealthier farmers will purchase tractors for private and contract work. Government assistance can most effectively be provided by helping the tractor owners and their employees to obtain adequate training in the maintenance and use of their equipment. Easy credit for the purchase of tractors, or a subsidized rate of tractor hire, is likely to result in inefficient use of expensive equipment and waste of farmers' resources.

Zimbabwe

Chibi is a communal "smallholding" farming area about 370 km south of Harare, partly in Zimbabwe's ecological zone IV and partly in zone V. This is a semiextensive farming region with a unimodal but rather spread-out rainfall distribution averaging 450–650 mm/year. Although the part of the area with less than 600 mm rainfall would come into the arid zone, it appears that the altitude moderates the temperature and evapotranspiration sufficiently to bring most of it into the subarid zone. However, Collinson (1989) points out that the rainfall regime is highly variable with a 20% probability that any 15-day period in the middle of the growing season in January–February will receive less than 45 mm of rain. Similarly, the length of the growing season is variable, ranging from fewer than 120 days to more than 165 days. Thus, farmers must manage both the uncertainty of the length of season and the chance of a mid-season drought at the height of the growing season.

Rohrbach (1987) has reported on a number of surveys carried out in Chibi in 1986. Individual holdings average 2.4 ha of which 2.15 ha were planted with summer season crops (Table 8). During the 1985/86 cropping season, on average, almost 60% of the 2.15 ha under crops was allocated to maize; 13% to groundnuts; 12% to finger millet; and 16% to "roundnuts" (presumably bambara groundnuts), sorghum, pearl millet, and other minor crops. Maize–finger millet and maize–groundnut intercrops were common, although they accounted for less than 10% of average cropped area,

Table 8. Cropping patterns at Chibi, Zimbabwe, 1974 and 1985.

	1974 (*n* = 46)			1985 (*n* = 106)		
Crop<super>a</super>	Average area (ha)	Total area (%)	Farmers growing (%)	Average area (ha)	Total area (%)	Farmers growing (%)
Maize	1.15	42.3	93	1.27	59.3	100
Groundnut	0.46	17.1	74	0.28	12.9	69
Sorghum	0.31	11.3	43	0.09	4.2	30
Pearl millet	0.30	11.3	37	0.07	3.4	15
Finger millet	0.29	10.6	61	0.25	11.6	70
Roundnut	0.12	4.4	46	0.14	6.4	78
Other	0.05	3.1	36	0.05	2.3	36
Total	2.68	100.1	–	2.15	100.1	–

Source: Rohrbach (1987, table 4).
a Maize, groundnut, and finger millet data incorporate intercrops.

Between 1974 and 1985, the average area planted per household declined by 20%, but the average maize plantings increased by 10%, mainly at the expense of the more drought-tolerant traditional cereals, sorghum and pearl millet. Rohrbach (1987, p. 159) suggests that the dominance of maize reflects its importance as the principal staple. Maize is strongly preferred both for its taste and ease of processing. Finger millet remains important as the major ingredient in beer and is recognized as valuable for its drought tolerance. Groundnuts are widely recognized for their nutrient value, particularly for young children. However, groundnuts are being replaced by manufactured cooking oils, particularly by younger families, for reasons of taste and convenience. Areas of sorghum and pearl millet are declining as the rising incidence of bird damage and the difficulty in processing these crops for consumption offset their drought-tolerant characteristics.

Maize is widely viewed as the principal potential source of cash earnings and the most profitable crop. This perception seems to have been supported by government price and marketing policies. Up to 1971, nominal producer prices for maize were maintained slightly above those for sorghum and groundnuts, perhaps because maize was mainly grown for the market by large-scale commercial farmers. After independence in 1979, nominal maize prices were doubled between 1979 and 1981, and the ratio of maize to sorghum prices rose by 40%. Marketing facilities in Chibi were also greatly improved, so that farmers could get their surplus crop to market. At the same time, farmers greatly increased their plantings of the new higher-yielding hybrid seeds. Although they apparently considered that increased fertilizer use was too risky with their uncertain rainfall regime, maize yields more than doubled from 420 kg/ha in 1975 to over 1000 kg/ha in 1985 (a high rainfall year). As a result, maize sales from the region rose from very little before 1979 to nearly 20 000 t in 1985. However, poorer rains in 1986 reduced yields and sales severely (Rohrbach 1987).

Collinson (1989) stresses the importance of livestock for the maintenance of soil fertility in this farming system.

Low fertility of the granitic sands was managed by crop rotation around an area of fallow and by the use of animal manure. As population pressure has increased, areas in fallow and grazing have been reduced. The resulting reduction in cattle numbers and in manure undermined farmers' strategies to maintain soil fertility and, through the loss of draft power, had made them more vulnerable to rainfall crises.
Only 45% of households owned cattle in 1981, compared to 56% five years earlier. Farmers had to choose between keeping cows for milk, or oxen for ploughing, and followers for replacement. The unorthodox answer was to keep the cows and use them for ploughing. Cattle-owning households ploughed for virtually the whole community. This prolonged the overall time taken to establish crops, lowered the quality of work on the seedbed and put heavy pressure on the cows. Such stresses were believed to reduce cow fecundity and threaten future milk supplies and the replacement of animals.
The higher incomes and yields reported for cattle owners demonstrate the power of higher resource endowments in managing the environment. At approximately 20 bags [1800 kg] per hectare, the maize yields of cattle owners were roughly twice as high as those of non-owners in the 1980–81 survey. Cattle owners also had a much lower failure rate for groundnuts. Owners showed more thorough seedbed preparations. For example, 60% of their maize plantings were winter ploughed, compared to 20% by non-owners, 40% of their plantings were harrowed, compared to 20% by non-owners, 90% of owners reported using cattle manure, compared with 15% for non-owners. Finally the proportions of maize and groundnuts planted by owners before Nov. 10 were 40% and 58% respectively, compared with 20% and 26% for non-owners. Differences in resource endowment were tempered by social cohesion; although cash payment had become the custom, owners still honoured the obligation to make their animals and equipment available to non-owners for land preparation in a relatively timely way.
The downward trend in cattle holdings has exaggerated problems of timely cultivation and the quality of work. The ability of Chibi farmers to adjust to unreliable rainfall and lowered soil fertility was reduced. Farmers in Chibi South used various devices to counter increasing animal nutrition problems; the use of cows for plowing in winter when the animals are in dire condition, the use of maize stover for dry season feeding, and very late planting of maize and bulrush millet to provide standing fodder. These measures

identified leads for research; the pressing question was whether draft animals could be held in the Chibi system over the long run.
This description of Chibi may be fairly representative of many of the regions of uncertain rainfall and high and increasing population density where maize is the dominant crop in eastern and southern Africa.

Zimbabwe as a whole, however, achieved a major increase in maize production in the years after 1979. In 1985, production reached a record level of over 3 million t, which was double the current domestic consumption level. Most of this increase came from the communal areas, which tripled their maize production to 1.6 million t between 1979 and 1985. By contrast, commercial production declined during the same period.

As outlined for Chibi, this "Green Revolution" in maize production seems to have been due to the same combination of factors that triggered the Green Revolution in Asia. That is, high yielding varieties in the form of maize hybrids that were well adapted to the environment, improved marketing facilities, and perhaps most importantly, farmers' perceptions of increasingly profitable crop price levels. Also, not so much in Chibi, but in other communal farming areas, there were large increases in fertilizer applications to maize and some increases in the use of crop-protection inputs and access to credit (Rohrbach 1987, p. 145). A missing factor that was present in Asia was that there was only limited use of irrigation in the communal areas in Zimbabwe.

The very large maize crop that was marketed mainly from the communal areas in 1985, probably largely as a result of the doubling of the maize price, seems to have been an embarrassment to the government, as maize storage facilities were overwhelmed, and there was a large surplus stock over national requirements. Considerable efforts were made to find profitable export markets, but it appears that much of the crop had to be exported at a loss, increasing the grain marketing board's, and eventually the government's, deficit considerably.

Synthesis

The subarid savanna zone is an important part of the main cereal-producing belt of Africa. In West Africa, it has been traditionally characterized by the production of sorghum on the heavier soils with some pearl millet on the lighter soils. These dominant crops are usually planted mixed, often with cowpeas, which are planted at low density, mainly for forage for livestock, but also for grain. Most farmers plant a sufficient area of cereals (usually about 0.2–0.3 ha/person) to provide the basic subsistence diet, and add a cash crop, usually groundnuts in Senegal and Nigeria, but cotton in some areas. These are grown in rotation with the cereals.

Farmers often plant small plots of maize, sometimes mixed with millet or sorghum, on the manured land round the homestead or village. This maize usually produces the first food after the "hungry gap" in the form of green cobs, but maize is more susceptible to drought than sorghum or millet. On the heavier soils, particularly where manure or fertilizer, or both, are available, additional maize may be planted, usually partly replacing sorghum or mixed with it. Small plots of rice are often planted in the seasonally flooded swamps.

This pattern extends across West Africa from Senegal as far as Chad, and includes much of the 6 million ha of sorghum in northern Nigeria.

Many farmers throughout this zone own livestock, mainly cattle, sheep, and goats. Cattle are used for plowing, and horses and donkeys are used for transport and, in Senegal and Burkina Faso, for planting and cultivating groundnuts. Livestock are often tended by paid herdsmen, frequently Fulani, who may be paid in milk or other forms. Where population pressure is heavy, so that continuous cultivation is practiced, as in the "groundnut basin" of Senegal, and around Kano in northern Nigeria, farmers have attempted to expand their manured area. They may do this by moving the cattle boma around the fields, or by paying or otherwise persuading the Fulani or other herdsmen to tether their cattle on the stubble in the dry season. Where insufficient manure is available and soils are inherently sandy and poor, as in parts of Senegal's "groundnut basin" and on the Mossi Plateau in Burkina Fasso, severe soil impoverishment and erosion can occur.

Although some phosphate fertilizer is applied to groundnuts in Senegal, and both phosphate and nitrogen are used on cotton and maize, little fertilizer is applied to the sorghum or millet crops; however, they may obtain some benefit from the phosphate residues after maize, groundnuts, or cotton.

In the subarid areas of Ethiopia, Somalia, the Sudan, Tanzania, and northeast Uganda, dark cracking clays (mainly vertisols), are widespread. Sorghum, mainly planted as a pure stand, is the principal crop in these areas, although a little maize may be grown. In Sukumaland, northern Tanzania, cotton is an important cash crop, and rice or sweet potato are planted in seasonal swamps or swamp fringes. Cassava is increasingly planted where soil fertility is declining.

In southern Africa, maize appears to have replaced sorghum and pearl millet throughout much of the area, but finger millet is still widely grown, mainly for beer, and sorghum and pearl millet are still widespread in the drier parts of Botswana and western Zimbabwe. Because maize is generally considered to be more susceptible to drought than sorghum or the millets, and because of the uncertainty of the rains in southern Africa, the possibility of persuading farmers to reverse the trend of replacing sorghum and pearl millet with maize has been widely discussed in recent years.

Considerable research has been undertaken, both by national researchers and by international agencies, particularly ICRISAT, to breed high-yielding hybrids or varieties of sorghum and pearl millet that are acceptable to farmers. By 1994, 15 improved sorghum varieties and 5 pearl millet varieties with ICRISAT involvement had been released by national research programs in southern Africa. In Zimbabwe, 37% of the total sorghum area was sown with variety SV2, and in Namibia about 35% of the millet area was sown with variety Okashana 1 in 1992/93 (ICRISAT 1994, p. 52). However, as described in the case of Zimbabwe, government cereal pricing and marketing policies generally seem to have favoured maize over other cereals, and farmers' taste preferences and perceptions of profitability also seem to favour maize.

Chapter 7: Subhumid savanna zone

The subhumid savanna is another agriculturally important zone throughout the African savanna (Fig. 19), with perhaps the largest potential for annual crop production, particularly cereals, in the savanna. It extends from southern Senegal, Gambia, and Guinea, through southern Mali and Burkina Faso, northern Cote d'Ivoire, Ghana, Togo, Benin, central Nigeria, Chad, Central African Republic, into southern Sudan, most of Uganda, and western Kenya. Large parts of Tanzania, Mozambique, northern Zambia, southern Zaire, and Angola are also included.

Although the soil associations in this zone are complex and there are many varied catenary sequences, as in the subarid zone, the soils in a large part of this zone are classified as alfisols, although there are considerable areas of ultisols in Guinea and Uganda, and oxisols in Angola, Central African Republic, and Zaire (see Fig. 5).

The natural vegetation in this zone is characterized by Isoberlinia spp., and Burkea africana and Afzelia africana are also common in West Africa, and in the miombo woodlands, Brachystegia spp. and Julbernardia spp. Protected species are Parkia clappertoniana and Butyrospermum spp., the shea butternut, which is widely used as a source of fat and oil. Timber trees include Milicia (formerly Chlorophora) excelsa and Entandrophragma spp. Tall grasses include Andropogon gayanus, Hyparrhenia spp., and Pennisetum spp. (Okigbo 1986, p. 98).

The Gambia

Haswell's (1953, 1963, 1975) studies of the development process in the village of Genieri in the central Gambia over the years from 1949 to 1974 are unique in following the changes in a village community over a quarter century. This village is probably fairly typical of many of the Gambian villages that border the Gambia River, and of villages in the neighbouring Casamance and Sine–Saloum regions of southern Senegal that border rivers in that country. However, the increasing importance of swamp rice cultivation in Genieri means that it is not typical of villages in the region that rely entirely or mainly on rainfed agriculture. The farming system in Genieri is shown in Fig. 20.

In this village, groundnuts and a little early millet were grown by individual men, mainly on the more fertile brownish sandy loam soils near the village, whereas late millet was grown communally by the men after clearing bush on the less fertile grey soils above the scarp. Women were entirely responsible for both upland and swamp rice that provided about 80% of the village's food grain supply. Table 9 outlines the land and labour use for the crops in 1949, for this village of 483 people (220 males and 263 females).

Table 9. Land and labour use and crop yields on Guinea savanna, Genieri, Gambia,

1949.					
	Total area (ha)	Average plot size (ha)	Average yielda (kg/ha)	Average labour,b all operations (hours/ha)	Average return to labour (kg/hour)
Grey soils (above scarp)					
Late millet	35.8	1.15	256	544	0.47
Grey and brown soils (below scarp)					
Early millet Sorghum *Digitaria exilis*c Maized Groundnut	5.7 4.1 32.6 2.3 105.8	0.63 0.48 0.43 0.06 1.05	319 177 115 – 541	660 166 116 786 650	0.49 1.07 0.99 0.91 0.83
River flats					
Upland rice Swamp rice	28.0 69.7	0.17 0.32	340 991	2051 1534	0.17 0.64
Source: Derived from Haswell (1953, pp. 32 and 39). a Cereals as grain, groundnuts in shell, and rice paddy. b Millet, sorghum, and groundnuts — men; Digitaria, maize, and rice — women. c "Hungry rice" grown in rotation with groundnuts. d Maize grown in house compounds to take advantage of refuse and dung. Maize cobs are usually eaten green.					

Haswell (1975, p. 42) points out that the average return to labour from groundnuts in 1949 was 0.83 kg/hour. More work put into the crop would probably not have increased the return much. Because land was not an overall limiting factor, although there was some shortage of the more fertile brown soils near the village, she suggests that returns to labour were more important than yields per hectare. However, she stresses that

In traditional farming practice, labour was virtually the only input. "Scarcity" of season, however, is an overriding factor and, in interpreting use of labour and returns to labour, due attention has to be paid to the times at which labour can be used. Labour in the busy seasons soon after the rains break, and during the first weedings particularly, has opportunities of being much more productive than labour at other seasons. But farmers' decisions were also constrained by social factors. The villagers gave expression to the kind of pressures which their peoples were experiencing at that time. "There are many reasons for limiting an area. You may clear a large area which you may not be able to ridge all. Sometimes you lack the seed to cover it all. Sometimes you are overcome by weeds through illness or accidents. All these do happen. Even if you are not sick, continuing rain disturbs your weeding and you find yourself behind time."

Activity on the land before the first rains consisted mainly of slashing and burning regenerated "bush" and was negligible; during the months of June and July, however, there was an all-out effort among the men to plant and weed the new crop. Farming then slackened during the growing season when the rainfall is normally heaviest; in October activity was again accelerated as the groundnut harvest approached, and was maintained until the crop was safely led [that is stored]. Although their efforts on farming were also concentrated largely within the limits of the rainy season, unlike the men, the women maintained a high pitch of activity almost throughout the season. Confined as they were to the heavier rice soils, considerably more work was necessary in pre-planting operations; the breathing space they might otherwise have had during the growing season was taken up with the additional operation of head-loading rice seedlings for transplanting in the swamp, followed almost immediately by the work of harvesting the early crop of upland rice.

Persistently poor feeding and lowered resistance to disease adversely affected the quality of work of some farmers, and many resorted to the use of "medicines" and adopted superstitious practices, consulted "wise men" and purchased expensive fujus to "protect" themselves and their crops.

In describing the nutritional situation in the village during this "hungry-gap" period, which is so widespread throughout Africa, Haswell (1975, p. 100), continues by quoting one of the Medical Research Council nutritionists.

Gamble (1955, pp. 108–112) observed in his study of food supplies in Keneba in 1950–51 that during the latter part of the dry season in March–April a number of changes in the types of meals gradually took place. There was a decrease in the amount of rice eaten, gruel, which uses less grain, being served with greater frequency, and even bran — a sign of food shortage — being used in the cooking. In May the mangoes ripen and children begin to eat considerable quantities of the fruit. Towards the end of May one saw the first clear signs of a food shortage. By July products of the "bush," leaves and fruit, became more frequent ingredients of the meals. In early August one found that there were a number of people who were not getting even one normal meal a day, and were living on boiled leaves and groundnuts .... Diarrhoea and various stomach troubles increased noticeably in the village. One found women collapsing by the roadside on the way back from the swamps and having to be helped home, the cause apparently being too much work with too little food .... In most compounds local grain supplies were practically exhausted.... The latter part of August was perhaps the time of severest hunger. Ten per cent of the people had two meals a day, sixty per cent one meal, and thirty per cent no adequate meal, i.e. no meal with one of the staple grains. The characteristic food of the period was boiled leaves and baobab seed, occasionally with dried duto (Cordyla africana "wild mango" fruit). One sometimes found old men pottering about their farms, up-rooting and chewing the not very ripe groundnuts.

It is interesting that mechanization trials on previously farmed land showed that the capital and running costs of a tractor were prohibitive in these conditions. Also the crop yields obtained, of 360 kg/ha from groundnuts grown using the tractor on brown sandy soils, 158 kg/ha from groundnuts grown on grey soils, and 70 kg/ha from *Digitaria exilis* on grey soils, compared unfavourably with those obtained by the local people under their traditional system of hand-hoe agriculture (Haswell 1975, p. 55). It appears that these trials represent a considerably more accurate comparison with the neighbouring traditional farming practices than the comparisons so often made between yields obtained, under highly artificial conditions, on experimental farms, with average farm yields, which are usually unreliable anyway.

Another type of mechanization that had been practiced by a few farmers for many years was ox cultivation. The Mandinka people of Gambia were not traditionally cattle keepers, and the few cattle they owned (no more than a dozen in 1949) had been mainly looked after by itinerant herders such as the Turanko people. Gradually, some of the farmers with the larger families began to acquire more cattle, mainly apparently as a form of bank account or insurance. Haswell (1975, p. 130) quotes one farmer.

I bought these cattle to safeguard my money in case of poor price for groundnuts, and an emergency. I can sell a cow and get some quick attendance without having to go to any trader or moneylender.

By 1962, the number of cattle owned by villagers was over 150 head. The government Department of Agriculture had started a number of ox-plowing schools, and 20 schools were operating with 236 pupils. There were some questions whether the widespread trypanosomiasis might cause losses of plowing oxen. The local Ndama cattle had some tolerance to trypanosomiasis, but the fears that this might break down under the stress of plowing did not apparently materialize. The number of oxen and plows in the village gradually increased, mainly for groundnut growing. Donkeys were also used for groundnut planting and transport. There appear to have been some small increases in yields from plowing, for example, late millet yields increased from 329 kg/ha under hand cultivation to 527 kg/ha on plowed land, but the main effect seems to have been to reduce the effort and drudgery of hand cultivation.

There was an actual decrease in the area cultivated per person from 1949 to 1974, but there was a substantial increase in both food crop and total agricultural production (Haswell 1975). The main increase was in groundnut production, which rose from 31.5% of total production in 1949/50 to 46.0% in 1973/74. In the same period, the food production rose from 165 to 262 kg paddy equivalent per person per year — because rice was the main staple food, other foods were converted into paddy rice equivalents. This increase was mainly due to larger in-swamp rice production. On the other hand, there were no increases in millet, sorghum, or *Digitaria*, which only contributed 3.8% of total production in 1974. Haswell continues.

Bush farms above the scarp were found to produce total crop failure after 4–5 years cropping under late millet, and required a long period of bush regeneration before they were considered worth bringing under the hoe again.

Haswell draws attention to the wide variations in total agricultural production per person per year between the different compounds in the village. In 1961–62, one compound with eight members produced a total of 641 kg paddy equivalent per person, of which 27.1% was groundnuts. The poorest compound (Number 31), with 15 members, produced only 140 kg paddy equivalent per person, of which 62.8% was groundnuts and only 52 kg was food crops, well below the minimum subsistence level of about 200 kg/person per year. She adds (Haswell 1975, p. 123):

Compound 31 [did not] have sufficient men in the work force to cultivate the 1.5 hectares of groundnuts planted, so labour was hired to assist with the "groundnut farm," money being borrowed from a trader in Kaiaf to meet this expense; still the combined harvests of rice and groundnuts far from met the requirements of the household in that year even at the barest physiological minimum, and with no alternative employment opportunities open to them, this family became indebted simply to buy the daily bread. Poverty was more apparent in [compound] 31 than in any of the other sample compounds; shelter was of mud and thatch and badly in need of repair, and possessions were pathetically few. Overall, however, the figures indicate a slow but steady annual increase of 2.0% per person for food crops and 3.0% for total agricultural production, from 1949 to 1974. One of the more obvious ways in which this increase in prosperity showed itself was in the number of living huts with corrugated iron roofs, which increased from none in 1949 to 84% in 1974 (Haswell 1975, p. 177).

Mali

De Wilde (1967, pp. 301–336) provides an interesting description of the spread of cotton cultivation in Mali. Cotton growing was first encouraged by the Compagnie francaise pour le développement des fibres textiles (CFDT), now the Compagnie malienne pour le développement des fibres textiles (CMDT), in the Koutiala region east of Bamako. The Mali government has since made CMDT responsible for all the agricultural extension work in the south Mali region under the Ministry of Rural Development. From the beginning, a strong emphasis was placed on the use of manure for cotton growing, and farmers were provided with free oxen and equipment on loan for 2 years, provided that they applied about 10–15 t/ha manure on their cotton land. These large quantities of manure appear to have been too much for most farmers to produce and transport to the fields, so this program does not seem to have continued for more than a few years. Artificial fertilizer was also recommended, as the combination of manure and fertilizer was found to be particularly effective in increasing yields. In 1962, 50 kg of ammonium sulfate and 75 kg of triple superphosphate were recommended, at a cost of about US $18. In 1963, the cost was subsidized to US $12, which led to a large increase in its use.

Following a consultancy mission by Norman and others (IER 1977), the Malian Government decided to start an enlarged program of farming systems research (FSR) in southern Mali. Part of this program began in three villages near Sikasso, with support from the Government of the Netherlands, and has been reported by the Institute d'economie rurale (IER 1979 on), and by Kleene (1984, p. 131–138).

Another section of the program (described here) was supported by IDRC. It concentrated on Gladie, Monzondougou, and Sakoro villages, which are situated near the Sikasso–Bougouni road, and was also reported by the Institut d'economie rurale (IER 1979 on). Gladie village was selected because it represented a relatively advanced farming system with many households using animal traction (mainly ox cultivation), farmyard manure and fertilizers, and a considerable production of maize and cotton. Monzondougou represented an intermediate system, with some animal traction and cotton growing but little use of manure or fertilizers, and continued bush-fallowing of the outermost fields.

Sakoro represented a more traditional system with little or no animal traction, use of manure or fertilizers, or cotton.

Although the soils in all three villages appeared to be similar fine sandy loams of the alfisol group, shallow in places over plinthite or ironstone gravel, Sakoro had more severe soil fertility problems than the other villages (IER 1980). The mean annual rainfall recorded at the nearest meteorological stations was around 1200 mm for all three villages. An initial survey indicated that the criterion of ownership of animal-traction equipment correlated reasonably closely with the surplus production over subsistence achieved by each household. Also, although Gladie village had the most households owning animal-traction equipment, and these were usually the larger households, there was a considerable range of households from the wealthiest with equipment to the poorest with none. The same situation was found at Monzondougou, whereas at Sakoro, although there was little use of animal traction, there was still some variation between households, particularly in the size of the households and the number of cattle owned.

At Sakoro, it was found that apart from the usual "champs de cas," around the houses, where maize was grown using the accumulated fertility from dung and refuse, the upland soils within about 6 km of the village had not been cropped for many years. The principal crops of sorghum and millet, with cowpeas intercropped at wide spacing, were grown after bush fallowing in the zone about 6–8 km from the village, together with some small plots of groundnuts, bambara groundnuts, and *Digitaria exilis* ("hungry rice" or *fonio*). The women also cultivated rice in the seasonal swamps near the village. They had the right to sell this rice as their main source of money. The yields of sorghum and millet were found to be about 350 kg/ha. The survey had also indicated that 80% of the households were below self-sufficiency in food production.

Following the usual FSR methodology (see, for example, Zandstra et al. 1981), several field experiments were designed in conjunction with the farmers, and carried out by the farmers themselves. These included the local maize variety, which was grown as a field crop for the first time on the unused land near the village, with various combinations of farmyard manure and fertilizer. It was found that the crop virtually failed without manure or fertilizer, and even with either manure or fertilizer yields were poor. On these soils, however, a combination of a small application of 2–3 t/ha of manure (which was available in the village, but had not been used previously) with the recommended rate of compound fertilizer (100 kg/ha) and urea top-dressed at 100 kg/ha gave yields of over 4 t/ha of dry grain on some farms.

The extension staff of the CMDT were fully involved in the research at all stages. The CMDT had introduced a scheme for providing maize seed and fertilizer on credit, together with advice to farmers, and they undertook to buy back the maize crop at the government minimum price, which was fixed at 80 CFA/kg (about US $0.30/kg).

A number of farmers also started using animal traction. Each year, an increased number of Sakoro farmers took advantage of this scheme and, by 1985, over 20 ha of maize were being grown. The first effect was to provide a food surplus for those households that grew maize successfully, and several householders sold some of their surplus maize. Before they became self-sufficient in food, Sakoro farmers had never been willing to grow cotton, but once they achieved food self-sufficiency, some farmers started growing cotton and groundnuts in rotation with the maize. The residual effects of the manure and fertilizers benefited these crops, and satisfactory yields were obtained.

In 1985, the CMDT extension workers and the IER's FSR team together decided to extend the testing of some of the technologies that had been adopted by the Sakoro farmers into four additional villages in the Bougouni zone. A diagnostic survey had indicated that these villages probably had similar problems and conditions to Sakoro, so technologies that were successful in Sakoro should have a good chance of being successful in these new villages.

Although it is still too early to assess the results, present indications are that farmers in these villages are enthusiastically adopting the maize–manure–fertilizer package after doing simple trials on their own farms. This work is organized and carried out by the CMDT extension workers responsible for the villages, with some advice and monitoring by the FSR team. If this preextension stage proves successful, it is proposed to train additional extension workers to organize preextension tests in other villages.

In Gladie village, on the other hand, it was found that a group of about nine households had already developed a highly productive farming system well adapted to their own needs and conditions. This system was based on a rotation with cotton followed by maize intercropped with millet, which could be followed by sorghum or groundnuts, then back to cotton. The cotton and maize–millet received farmyard manure and fertilizer, and animal traction was used for plowing and carting manure. Crop residues, in the form of maize, millet, and sorghum stalks were carted to the cattle *bomas* on higher land for manure production during the cropping season, and temporary *bomas* were made in the cropped area so cattle would produce manure there in the dry season. The women grew rice in the swamps.

Crop yields were high, averaging about 2.5 t/ha seed cotton, 3.5 t/ha maize, 1.5 t/ha millet, and 1 t/ha sorghum in a good year. Gross margin analysis at current input and output prices indicated that this system was highly profitable. These households had a considerable surplus of cereal production over current needs, some of which was sold together with the cotton, and much of the profit appeared to be invested in cattle, of which several householders owned large herds. In general, it was found that the larger households were able to acquire animal-traction equipment, which seemed to be the key to the success of this system. At the other extreme, there were some small households in this village, with perhaps a man or woman with young children, or an older person alone. These households could not afford the plow and two oxen needed to expand their area under cultivation and were, therefore, stuck in the vicious circle of poverty and intermittent hunger often accompanied by sickness so common throughout Africa. One farmer even resorted to cultivating a steep and rocky hillside, despite extremely low crop yields and severe erosion, apparently simply because fewer weeds grew on these rocky slopes, so his labour for weeding was reduced.

Because the farming system practiced by some farmers in this village was more advanced than in Sakoro, it proved more difficult for FSR to make much contribution to productivity. Shortage of good quality forage in the dry season was identified as a limiting constraint, and forage cowpeas in pure stand appeared to be one approach that was popular with some farmers. Upland rice was another technology that was adopted by some farmers, despite the risks of dry spells during the growing season.

Burkina Faso

Working in the ICRISAT project, Matlon (1984, pp. 99) gave preliminary results of a limited number of researcher-managed trials or demonstrations of the traditional sorghum or millet intercropped with cowpeas or groundnuts. In one trial on sorghum intercropped with cowpea in Koho village in 1982, with an annual mean rainfall of 950 mm, he found that net returns per unit area could be increased by an average of more than 60% as cowpea density was increased. The yield of cowpeas could be further increased by insecticide treatment, but he found that this treatment was uneconomic under intercropping conditions. Farmers were invited to comment on the trial.

Farmers were generally unimpressed with the increasing aggregate production brought about by increased cowpea density. They pointed out that the risk of animal damage was considerably greater at high densities. They also pointed out that labour requirements for weeding would be substantially greater with a high population of the rampant local varieties of cowpea and that the use of animal traction for weeding and ridging would be impossible. Farmers also observed that the substantial reduction of yields for sorghum (in their view, the priority component in this cereal–legume mixture) was unacceptable. In short, they felt that the possibility of higher financial returns from cowpeas grown at high densities did not offset the disadvantages and that the traditional density better met their objectives and was more consistent with their available labour.

Commenting on the sorghum–groundnut mixture, farmers explained that they considered groundnut the priority crop in the system. They noted that competition for light at high densities of sorghum forced the groundnut plants to grow upward, with reduced rooting and nut formation. They also criticized the spatial arrangement of groundnuts as being too close to allow adequate nut filling. In conclusion, they recommended a planting pattern that would increase the proportion of groundnut in the mixture, give greater room for each groundnut plant, and substantially reduce shading from sorghum.

As a result of the input from farmers, together with the returns analysis, the accent in subsequent on-farm trials of intensified cereal–legume mixtures has been shifted to groundnut-based systems. Planting patterns were modified to reflect the objectives expressed by the farmers, and early maturing varieties of sorghum and millet were sown late in some treatments (an alternative not now available to farmers) in an attempt to increase sorghum densities without adverse effects on the groundnut.

Matlon's experience with these on-farm trials illustrates one of the valuable aspects of on-farm research — the possibility of both involving the farmers in trial design and implementation and getting their views on the results.

Nigeria

Norman and his colleagues' work in describing the farming systems in several areas of northern Nigeria has already been mentioned (Norman et al. 1981). For example, they present the following data on complex and nuclear family units in the Zaria and Bauchi areas (Table 10).

Table 10. Characteristics of complex and nuclear family units (economic units), Nigeria.

	Zaria		Bauchi	
	Complex	Nuclear	Complex	Nuclear
Percentage of families	49.0	51.0	35.6	64.4
Size of family	10.9	6.2	7.5	5.1
Number of male adults	3.0	1.3	2.2	1.2
Farm size (ha)	5.4	2.6	4.5	3.6
Area per resident (ha)	0.5	0.4	0.6	0.7
Area per male adult (ha)	1.8	2.0	2.0	3.0
Dependent:male adult ratio	3.6	4.8	3.4	4.3
Age of family head	–	–	48	42
Average number of cattle	4.40	0.00	1.28	1.00

Source: Derived from Norman et al. (1981, tables 6.2 and 6.13).
Note: Mean rainfall 1115 mm/year at Zaria and 1 102 at Bauchi. Population density medium at Zaria and low at Bauchi.

They discussed the breakdown of the traditional complex family units containing more than one married man plus dependents into simple nuclear family units with just one married man plus dependents, which is occurring rapidly (Norman et al. 1981, p. 21). This seems to be a complicated process to which many factors of so-called "modernization" may contribute and is thought to be having substantial effects on farm mechanization. It appears to be considerably more difficult for the smaller nuclear families to acquire animals and equipment for animal traction than for the larger complex family units. Although, in theory, it would seem possible for the smaller families to acquire animals and equipment in proportion to their size, in practice it appears that the larger, complex families own more cattle in proportion to the family size and are able to acquire equipment more readily than the smaller families.

In recent years, prices of cash crops have increased relatively less rapidly than those for animals and equipment. This slows down the adoption of animal draft power, and diminishes the beneficial interaction between crop production and livestock management. It also creates the danger of further aggravating the dual economy that is developing between those farmers who have oxen and equipment and those who do not [Norman et al. 1981, p. 70].
In an interesting and useful discussion of labour in West African agriculture, they suggest that labour, and not land, appears to be the major factor limiting increased agricultural production at present. They go on to point out that labour shortages are seasonal, and may cause severe bottlenecks to increased production at the busiest times of the farming year.

For example, they quote data for Zaria and Bauchi (Table 11) that show that over 50% of the total labour time on the farm is concentrated in the cropping season from May to August in Zaria or June to September in Bauchi. Between one-third and one-quarter of this time is spent during the peak month (June in Zaria and July in Bauchi). Even during the peak month, male adults worked for an average of 7 days off the farm, and they worked for an average of 5.0 hours/day on the farm in Zaria and 5.3 hours in Bauchi. (An additional 0.5–1 hour was spent walking to and from the fields.) It is interesting that these farm working-hours agree closely with those recorded by Haswell (1975, p. 50) in Gambia of 5.1 hours for adult males, although adult females averaged 6 hours there.

Table 11. Indicators of seasonality of work, northern Nigeria.

	Zaria	Bauchi
Four busiest months	May–Aug	Jun–Sep
% of annual person-hours on farm	50	53
Peak month	June	July
Person-hours worked on farm	256	210
Days worked per family male adult		
Farm	17	19
Off-farm	7	7
Total	24	26

Source: Derived from Norman et al. (1981, table 6.13).

Norman et al. go on to describe the substantial amount of hired labour that was employed on these farms.These data indicate that, in northern Nigeria, women do less than 2% of the on-farm work (Table 12). Although Norman ascribes this to the northern Nigerian Moslem practice of keeping women in seclusion, elsewhere in West Africa Moslem women are not kept in seclusion to anything like the same extent (see, for example, Delgado [1978] for Burkina Faso, IER [1980 on] for Mali, Haswell [1975] for the Gambia) and they carry out a much larger proportion of the farm work. The fact that nearly 50% of the potential labour force in northern Nigeria does not do any farm work, even in the busiest bottleneck periods, seems strange in the light of Norman and his colleagues' suggestion that labour is the major limiting factor.

Table 12. Source of farm work (% of total person-hours).

Source of farm work	Zaria	Bauchi
Family		
Male adults	72.2	73.3
Female adults	0.3	1.6
Large children	8.9	9.4
Subtotal	**81.4**	**84.3**

Hired Hourly Contract Communal **Subtotal**	 8.6 9.1 0.9 **18.6**	 6.4 4.5 5.1 **16.0**
Total	100.0	100.3
Annual total person-hours on the family farm	1800	1317
Person-hours worked during the cropping season	900	658
Annual hours worked per male adult on and off farm	1166	1159
Source: Norman et al. (1981, tables 6.7 and 6.11).		

Table 12 indicates that some 16–19% of farm labour in Zaria and Bauchi is nonfamily labour. Whereas in Bauchi 5.1% is communal labour, this type of labour has almost disappeared in Zaria. Norman et al. (1981) ascribe this decrease in communal or group-organized labour to increased individualization through increasing contact with the modern world in Zaria.

Discussing land holdings, Norman et al. (1981, p. 36) emphasize that, throughout the West African savanna, individuals generally have only had rights to use the land under the traditional communal tenure systems. Legal ownership is normally held by governments. The right of use usually passed from father to eldest son, or in Moslem societies, the land was divided among the sons. Probably because of this system, and also because people using hand hoes were physically unable to cultivate more than 1–2 ha/worker, few large-scale inequalities in land ownership and use developed in West Africa. However, there are signs that this relatively equitable distribution may be changing in some countries, where powerful individuals or groups are attempting to gain control of large tracts of land. Some of this land may have been traditionally cultivated by smallholders, who may either have to pay rent to the new "landlords" or be dispossessed. This trend could cause very severe inequalities and stresses in rural communities.

The introduction of ox-powered and, particularly, tractor-powered mechanization may lead to attempts by a few individuals to acquire large land holdings. The national economy may benefit from the emergence of a group of larger-scale farmers, who can invest capital and increase their farm production more easily than smallholders, particularly where these farmers can acquire land that was previously unused and farm it well. Unfortunately, the land-use practices on some of the large farms that are being cleared and developed in Nigeria with the use of heavy, and often inappropriate, machinery are so damaging to soil fertility that the soil productivity may be severely harmed within a few years (Lal et al. 1986).

As population density increases, it appears that traditional communal systems of land tenure tend to break down, and initially the right of land use and, eventually, the land itself is bought and sold as it is in most parts of the world.

Uganda

Carr (1982) has described the agricultural trends from 1910 to 1970 in the three districts of Acholi, Lango, and Teso, which lie in the subhumid savanna zone of northern Uganda. The rainfall pattern varies from a bimodal distribution with a total of about 1 200 mm in two rainy seasons per year, March–June and August–November, in the south of this region or a unimodal distribution with about 900 mm in the northeast with one rainy season, April–October, and a dry season, November–March (Ker et al. 1978, p. 13).

Carr (1982, p. 4) points out that

The people of Acholi, Lango and Teso areas in north and eastern Uganda have shown themselves both innovative and adaptive in their farming practices over the past sixty years. Their most striking innovations have been the adoption of cotton growing on a very large scale, and the use of ox ploughs for land preparation. There have been, however, a number of other changes which indicate the flexibility of their approach to farming. These can best be indicated by describing the farming systems of three tribal groups at four points in their development, 1910, 1923, 1938 and 1969.
There are not a lot of quantitative data available for the earliest date but there are descriptions of the crops grown and the farming systems used. Cotton had just reached Teso and Lango by 1910 but was still unknown in Acholi. The first ox ploughs had been tried in Teso but had as yet had no impact at all on the mass of farmers and were unknown in Lango and Acholi. Land was normally opened to finger millet which was the dominant crop in all three areas. In Lango and Acholi this was interplanted with pigeon pea. In Teso groundnuts were common, but they had not yet become established in Lango and Acholi where sesame and cowpeas were the main subsidiary crops. Some sorghum was grown but maize was virtually unknown throughout the area as were cassava and sweet potatoes. The last were moving into Lango at this time and were so highly valued that one bundle of cuttings was accepted as a dowry (equivalent to four cows).
Although published data on crop areas were of doubtful reliability, they indicated clearly that between 1923 and 1969 farmers introduced four entirely new food crops — groundnuts, maize, sweet potato, and cassava — and a completely new cash crop — cotton — into their farming system and in some areas introduced ox-plowing. After the introduction of cotton, farmers soon found that it grew well on newly opened land, and if they kept it clean-weeded it provided a very suitable seedbed for finger millet, so cotton became the first crop in the rotation, followed by finger millet, which might be followed by a second cotton crop, or by sorghum or sweet potato. Later, cassava came in, usually replacing sorghum as the last crop in the rotation before the resting period, and it has become increasingly important in recent years. A few farmers planted groundnuts as the first crop, followed by cotton or sorghum in the second rains, or groundnuts were sometimes intercropped with cassava (Fig. 21).

Carr (1982, p. 7) points out that the Nilotic peoples of Acholi and Lango, where ample fertile land was available, traditionally cleared and hoed new land for each farmer in groups in exchange for beer.

In Teso, the number of ox plows increased from 282 in 1923 to 16 000 in 1938, when it was estimated that 90% of the new land was being opened by plow, and to an estimated 70 000 in 1969. Lango and Acholi were slower to adopt the plow, probably partly because the tsetse fly limited the number of cattle in part of the area, but the number of plows in Lango increased from 35 in 1923 to 17 000 in 1969 — numbers for Acholi are not available. Large numbers of livestock were kept (Table 13).

Table 13. People and livestock numbers in Acholi, Lango, and Teso districts, Uganda, 1963.

District	Population total ('000)	Cattle		Sheep		Goats	
		Total ('000)	Per holder	Total ('000)	Per holder	Total ('000)	Per holder
Acholi	340	135	2.66	63	1.24	116	2.29
Lango	403	371	5.24	96	1.35	219	3.09
Teso	552	660	6.57	48	1.48	222	2.21

Source: Ministry of Agriculture and Cooperatives (1963).

Although accurate data are difficult to obtain, it is clear that cotton production increased rapidly in all three districts, from none in 1910 to nearly 100 000 t in 1938 and about 120 000 t by 1970. Although the total areas under crops per person were hard to determine accurately, they were estimated at 0.8 ha in 1963. This figure includes double cropping the same field, so the actual area cultivated was about 0.6 ha/person, because not all fields were double cropped. Such data as are available suggest that before the introduction of cotton and ox plows about 0.4 ha/person was cultivated, so it is clear that farmers expanded their cultivated area per person considerably, mainly by growing cotton as an additional crop, and the introduction of ox plows assisted in this expansion. However, Parsons (1970, p. 134) points out that the Acholi and Lango farmers did expand their cultivated area per person to grow cotton, even before the introduction of ox plows.

The division of labour between the sexes has also changed. In 1910, the Langi men carried out all the work of preparing land and sowing food crops, while the women did all the weeding, and harvesting was shared between them. With the introduction of cotton, men still do most of the land preparation including plowing and planting both cotton and food crops, also weeding and harvesting cotton. The women do some of the land preparation and planting for food crops, all the weeding of food crops and share the harvesting. Men are still responsible for herding cattle. The cattle are mainly grazed on communal grazing areas and sometimes on the stubble after crop harvest. At night, they are kept in open *kraals* (small fenced areas) near the homestead. There is little systematic use of manure but oxen may be used for cultivation.

The agricultural extension service made considerable efforts to introduce other types of ox-drawn machinery in addition to plows to farmers over the years. These included weeders, seeders, and various toolbars, including the "Ariana" and the wheeled tool carriers named the "polyculteur" and "tropiculteur," but none of this equipment was adopted by more than a few farmers, despite the fact that prices were sometimes heavily subsidized (Starkey 1988).

Tractors were also purchased by a few farmers, mainly in Acholi, and a government tractor-hire service was established. From 1962 on, this was greatly expanded and tractor-cultivated group farms were also established. By 1966, a maximum area of nearly 14 000 ha was cultivated by the tractor-hire service and on group farms in the three districts, after which the area cultivated steadily declined despite heavy subsidies. Carr (1982, p. 46) concluded:

The tractor hire service has been a considerable burden on the tax payer (the losses on running costs absorbed the basic graduated tax of 161 000 heads of households in 1967). At the same time it has not appreciably increased output from those who have benefited from the service. The main reason for this is that it has only intervened at one point in the farming year, namely primary cultivation. It has not relieved any other labour bottlenecks so the overall acreage that a family can handle has not been materially changed .... As weeding, picking and sorting absorb over 80% of the total labour input for the [cotton] crop, and as the tractor hire service makes no contribution to these activities it would not appear to be meeting a critical need in the farming pattern. What it does appear to have done is to transfer resources from the poorer members of the community to those who are more wealthy.

Carr's overall conclusions from this study appear to have considerable significance for the future of agriculture, not only in Uganda, but throughout Africa. He points out that the most rapid expansion of cotton growing in northeast Uganda took place in the 1920s as a result of six events.

- Law and order were established and a stable administration decided to develop the country through the encouragement of peasant farms.
- The Uganda railway was built in 1907 and gradually extended, reaching Lira in 1929; with a network of feeder roads, this permitted low-cost transport of the cotton crop.
- Private traders were encouraged to buy, process, and export cotton at prices that provided adequate incentives to the growers to produce the crop.
- A cotton variety that was well adapted to local conditions and to simple management was available.
- The farmers were willing to fit an additional crop into their farming system, mainly by planting it after weeding their priority food crops, so that its labour requirements fitted into their pattern of labour availability, in a situation where land shortage was not a constraint. (The introduction and adoption of ox-plows,

particularly in Teso District, undoubtedly assisted farmers by reducing the labour requirement for opening land, thereby enabling them to almost double their areas under cultivation. Farmers using hand hoes also adopted cotton growing but were only able to increase their cultivated areas by about 50%.)

- Simple consumer goods were readily available and cash was needed to pay taxes.

As a result of these factors, cotton production from eastern and northern Uganda increased from very little in 1910 to an average of about 90 000 t in 1934–39, making a considerable contribution to the country's foreign exchange and, therefore, to its overall prosperity, as well as to farmers' incomes.

Although it is difficult to obtain data to confirm or deny this hypothesis, it is my understanding that farmers also grew cotton because the cash income that it provided not only enabled them to purchase their simple requirements and to pay taxes and school fees, but also because it gave them some insurance against the food-crop failures, due to drought or other causes, that happened every few years. Sometimes, their surplus cash would be used to purchase cattle or other livestock, mainly as a "bank on the hoof" to be sold later when the proceeds would be used to buy food when necessary, or might be stored in a hole in the ground or, more recently, in a cooperative savings account.

Although the main reason for the severe impact of the 1983–84 drought in Teso was the loss of nearly all the livestock in the district through raiding, an additional reason appears to have been the decline in cotton production because of marketing and other problems, so that production reached a low level of about 15 000 t from the three districts by 1980. Although farmers attempted to respond by increasing their production of cassava, some of which was sold, this does not seem to have compensated for the nonavailability of the cash income from the sale of livestock and cotton for buying food. At the same time, there were indications of declining yields throughout the area, and particularly in the heavily populated part of south Teso, caused by declining soil fertility.

On cotton marketing, processing, and pricing, Carr (1982, p. 70) comments

The ginners were ... favoured through "cost plus" pricing mechanisms which encouraged inefficiency, cut down competition and reduced the price to growers. At a later date government has protected and subsidised co-operative activities and eliminated any competitive element which might have provided improved services or prices to farmers. It has further given sole responsibility for marketing and latterly for price determination to the Lint Marketing Board as a means of protecting government's own interests and control over the industry at the expense of efficiency and cost effectiveness.

Uchendu and Anthony (1975) carried out a detailed study of some 45 farms in Teso District in the mid-1960s. Table 14 summarizes some of these data. Anthony et al. (1979, p. 131) commented on this study.

Ngora, Kumi and Bukedea Counties had population densities of 93, 68 and 64 people per square kilometre respectively in 1965. Pressure of human and livestock numbers had become critical in Ngora County. Some voluntary migration had taken place within and beyond the district to relieve pressure on the land, but by 1966 had virtually stopped.

Migration is a traditional method of adjusting growing populations to available resources, but provides no satisfactory answer once land is in short supply.

Table 14. Farm data, Teso District, Uganda, 1966.

	Serere–Soroti (southwest)	Ngora (southeast)
Number of farmers in sample	21	24
Persons per farm	10.2	6.2
Farm size (ha)		
Average	7.3	2.6
Largest	20.0	5.7
Smallest	1.6	1.0
Number of blocks per farm	1.1	1.3
Area under cotton (ha)	1.9	0.7
Area under all crops (ha)	5.6	2.5
Percent of holding cropped	77.0	94.0
Area cropped per person (ha)	0.6	0.4
Cash inputs (UGS)a	218	55
Labor input	(149)	(23)
Cash returns (UGS)a		
Cotton	1166	295
Groundnut	–	8
Other crops	20	13
Cattle	69	100
Gross returns	1255	416
Net returns	1037	361

Source: Uchendu and Anthony (1975, p. 132).
a The approximate exchange rate at that time was 8 Uganda shillings (UGS) = US $1.

Samples of progressive farmers interviewed by Uchendu and Anthony (1975) were found to have cropped 44% of their holdings in Serere and Soroti counties in southwestern Teso District and 57% of their holdings in Ngora County in southeastern Teso District in 1966. The corresponding sample of neighbors of the selected progressive farmers in Serere and Soroti counties cropped an average of 77% of their holdings. Continuous cropping had become the pattern in Ngora, and land could no longer be rested between crops. Grass filter strips were increasingly encroached upon, and some farmers cropped the whole of their cultivable land. In other parts of southern Teso, land was cropped for 2 or 3 years and fallowed for 2. In northern Teso, it was still possible to fallow for 3 or 4 years.

Land hunger in Ngora had created a market for land, and 9 of the 24 farmers interviewed in the county had rented land for cash payments. Farms were becoming fragmented. They were inadequate in size, and the area devoted to cash crops and the gross farm income correspondingly low. The net return per farm for the sample farmers in Ngora was only one-third of that of the sample in Serere and Soroti counties.

Ker (1966) described the agricultural practices in Bukedi District, Uganda, which lies immediately south of Teso District, and has a similar climate but, being nearer the equator, the two rainy seasons are distributed more evenly throughout the year, particularly in the south. The Iteso people in the northern Pallisa county practice the same farming system as their cousins in Teso, whereas further south in the district the systems, although varied, rely increasingly on bananas, maize, cassava, and sweet potato to supplement the staple finger millet crop. Cotton is important throughout the district, with a little robusta coffee in the south.

Based on data for 1963–64 from the Uganda Census of Agriculture (Ministry of Agriculture and Cooperatives 1966), Ker (1966, p. 56) calculated the total area of cultivated land in the district as 1375 km². Total livestock numbers were estimated as 160 000 cattle, 70 000 goats, and 20 000 sheep (no information was available on numbers of poultry, which are kept by most landholders).

On average, the 82 840 landholders in the district grew almost exactly 2 ha of crops each on 1.7 ha of cultivated land (Table 15). Of this area, one-third was under bananas, one-quarter under finger millet, and one-third under cotton, partly double-cropped following finger millet. The remainder was occupied by various combinations of cassava (grown by 50% of the holders); sorghum, maize, and groundnuts (each grown by 30% of the holders); sweet potato (22%); and beans (11%). Although there was some variation both in total size of holding and in cropping system between holders and between subcounties, the data indicate that the average cultivated area per person did not vary substantially. Although there are some questions about the accuracy of the livestock data, these would average about two head of cattle and one goat or sheep per land holder, but the distribution would be uneven.

Table 15. Average areas of crops per holder and per person in Bukedi District, Uganda, 1963–64.

Crop	Average per holder (ha)	Average per person (ha)
Banana	0.6	0.12
Finger millet	0.5	0.08
Miscellaneous food crops	0.2	0.04
Cotton	0.7	0.16
Total crop area	**2.0**	**0.40**
	0.3	0.08
Deduct half of cotton area for	**1.7**	**0.32**

intercropping **Average cultivated area**		
Source: Ministry of Agriculture and Cooperatives (1966).		

In 1963, the total population of the district was estimated as 433 000, and the land area was 4070 km², giving a population density of 106/km², or 1 person/ha. This made Bukedi the third most densely populated district in Uganda, after Bugisu and Kigezi districts. Although the total area of uncultivable land was not known, it could be as much as 50% of the land area, or 0.5 ha/person. This would mean that only 0.18 ha/person (0.5 - 0.32) would be fallow land. With the relatively poor soils throughout the district, and the existing farming system, much of the land was already overcultivated, crop yields were generally low, and soil deterioration was proceeding rapidly. In view of the high population increase rate — over 3% per year — unless intensive agricultural production methods are adopted, the only solutions appear to be for many of the increasing numbers of people to seek other employment, or to move out of the district. Both of these alternatives do, in fact, seem to be happening. One recent development (in the 1990s) that is contributing to food supplies is the intensive production of rice in some of the swamps in the district. It would seem to be of vital importance for the Ugandan Government and other agencies to concentrate applied field research and development activities on such areas that are under stress to find longer-term solutions.

Kenya

Although the interactions of altitude, and therefore temperature and evapotranspiration, with rainfall are complex in the highlands, parts of Kenya receive between 900–1200 mm rainfall/year and can be classified as subhumid, although, like southern Uganda, the rains in the central and southern equatorial area fall in two rainy seasons rather than one.

For example, part of the lakeshore savanna in Nyanza District has a rainfall of 750–1250 mm in two rainy seasons totaling about 120–150 days. De Wilde (1967, p. 122) indicates that part of this area has deep alluvial mbuga soils (mainly vertisols), which, although more fertile than other soils in the district, are difficult to drain and to work.

Population pressure in this area was already high in 1960/61, with about 143 people/km². It was found that an average of 1.32 ha was cultivated per holding, but 31.5% of the holdings averaged less than 1 ha in area, and 58.7% averaged less than 2 ha. Of the holdings, 62% were fragmented, with an average of 2.84 parcels/holding. In the past, many Luo men (about 24% in 1962) found employment outside the district, mainly in other parts of Kenya. This led to a shortage of farm labour in peak periods, although ox plows are fairly widely used in tsetse-free areas.

Although little information is given on the farming systems, it appears that maize and sorghum are important staples, with rice in suitable locations. Cotton and sugar cane are also widely grown, and some 5000 t of cotton lint and 4000 t of sugar cane were marketed in 1963.

Rauch (1993) has described the deterioration in this region caused by unsustainable farming practices and the severe 4-year drought that climaxed in 1984. Barren hillsides and deeply eroded gullies in parts of the area indicated serious resource degradation. Causes included overcultivation without attention to soil and water conservation, overgrazing, and overcutting of trees for sale, because of pressure on the land from population increase and slow change in traditional farming systems. In attempting to respond to this crisis, an organization named Mobilizing against Desertification (MAD) was formed by the local Catholic diocese. Nine tree nurseries were formed to assist reforestation, and a start was made on encouraging interested farmers to become "model" farmers. At the same time, local people were trained in sustainable agriculture practices to become extension workers working closely with the government extension workers. Within 4 years, 40 small clusters of farmers grouped round the model farmers were beginning to establish potentially sustainable farming systems throughout the degraded area. Rauch sums up as follows.

- All genuine development must imply self-development. The energies required for this process can be released through a bottom-up team model which releases the potential of individual participation through supportive mutual internal relationships, and strong external support linkages.
- Members of the MAD team claim that their experience has challenged and enriched them, which significantly contributed to the success of the programme.
- Sustainability of development efforts cannot be achieved unless sustainability is the main focus for a programme from its very beginning.
- No program can successfully work in isolation. Staff and participants need to consciously foster linkages within their milieu, including NGOs [nongovernmental organizations] and government extension offices.
- A participatory team model facilitates innovation and diffusion of technological adaptation outside the core area.
- Socio-economic and technical development must mutually support each other. There can be no progress toward holistic development in an atmosphere of competitiveness with or isolation from each other.
- Changes, whether physical, socio-economic, or cultural are often painful to human nature. Innovation becomes less threatening if someone walks with and supports the affected person, as do MAD supervisors through regular support visits to model farms.
- Flexibility on the part of funding agencies makes innovation possible.
- Careful planning and accountability are vital to success.
- Tree planting exercises alone cannot bring about permanent solutions to an impaired environment. Farmers ultimately hold the key to successful counter-measures to desertification, and
- MAD has not yet found solutions to all problems prevalent in the target area. Shortages of water pose the most serious threat to agriculture in South Nyanza. The situation is under investigation. Another situation which needs careful research and effective improvements is the lack of good roads. Poor roads inhibit communication and prohibit the establishment of adequate marketing systems.

The two districts of Elgeyo–Marakwet and Baringo lie north of Nakuru partly in and partly on the edge of the Rift Valley. Because much of this area has a rainfall of 1000–1250 mm, the area appears to come, at least partly, in the subhumid zone. However, the large variations in altitude in Elgeyo–Marakwet District — from 1000 m altitude and about 500 mm rainfall near the Kerio River on the floor of the Rift Valley, up to 3000 m altitude and over 1250 mm rainfall in the Cherangani Hills — lead to a great diversity of agroecological conditions in a comparatively small area. These need considerably more detailed analysis than is possible here, and many parts of Kenya have, in fact, been studied in detail. However, the development process that has been taking place in this area is of considerable interest and may have implications for similar areas elsewhere, so a brief description, mainly taken from de Wilde (1967, pp. 157–187) is included here.

The people of the two districts are mainly of the Kalenjin language group described by de Wilde as nilo–hamitic. In 1965, there were about 91 000 Elgeyo, 65 000 Marakwet, 103 000 Tugen, 20 000 Pokot or Suk, and a few Njemps. These numbers can be expected to have about doubled by 1995.

Although the part of south Baringo on the plateau on top of the escarpment is relatively fertile, with an altitude varying between 2000 and 2600 m, and has a good rainfall, suitable for permanent agriculture, most of the district lies in the bottom of the Rift Valley at 1000 m altitude or less, with a rainfall of only 500–750 mm/year. This part of the district is the scene of severe land degradation resulting from uncontrolled grazing of stock. L.H. Brown of the Kenya Department of Agriculture described it as follows (de Wilde 1967, p. 175).

Baringo District has in fact reached an "overgrazing end point" where most of the grass and the topsoil has already gone over large stretches of the country, and the ground is blanketed with thornbush, largely useless to man and beast alike, which cannot be eradicated without the expenditure of large sums of money .... This tragic situation has not been caused by overstocking alone. In Baringo, and in similar situations on the Elgeyo escarpment, and the lower slopes of the Cheranganis in West Pokot, it has also been aggravated, over a long period of time, by shifting cultivation on steep slopes with shallow soil without any effective soil conservation measures .... The general overall degree of deterioration ... is more severe than any deterioration of range recorded in, for instance, the USA in similar rainfall.

Over the years, many attempts were made to introduce grazing control into this district, but none of them appear to have achieved much success, and the deterioration of the environment continues. I do not intend to cover this pastoral system in detail here, but this represents one side of the picture.

The other side is represented by parts of Elgeyo–Marakwet. This district lies mainly on the highland edge of the Rift Valley, at an altitude of 2000–2600 m, but includes the steep escarpment and an area along the Kerio river at the bottom of the escarpment. Traditionally, it appears that most of the Elgeyo–Marakwet people used to live on the escarpment, tilling subsistence crops such as millet, sorghum, maize, and cassava in a form of shifting cultivation, and keeping livestock, mainly sheep and goats. Few data were available on their activities, as they were relatively inaccessible and neglected by the Department of Agriculture. However, the Marakwet living in the Rift Valley in the north of the district did develop some indigenous systems of irrigation, using streams that flow down the escarpment, and a rather intricate set of furrows and aqueducts, to irrigate crops, particularly maize, on the valley floor. Although the irrigated area only amounted to about 1000 ha in 1965, it appeared that there was some potential for expansion to about 4000 ha.

In contrast, de Wilde (1967, pp. 166–169) described the Elgeyo farming system as follows.

While the Elgeyo still clinging to the escarpment are said to be virtually as traditional and conservative as the Marakwet, a much higher proportion of the tribe has moved onto the high plateau country of the Irong and Xosop. Locations where they have shown a capacity for rapid change .... This mobility and change ... impressed us as one of the striking phenomena of Kenya's development in the last two decades. Initially the land in the higher reaches of the Division was used only for communal grazing of stock which could no longer be kept all year on the escarpment. The young men detailed to guard the clan herds by the elders, who themselves remained in the escarpment, gradually began to clear patches in the forest for food crops, primarily maize. Others who returned from wage employment on European farms or in the district's sawmills joined them in staking out land, particularly as they were unable to find land on the escarpment. Also, as more stock invaded the plateau and competition for grazing began, there was a progressive tendency to enclose grazing land too, first only for dry-season grazing and then more extensively. Enclosure, which began only in the late 'forties, was virtually completed in all of the highlands by the close of the 'fifties. It took place usually in the face of the strong resistance of clan and kokwet elders who wanted the land reserved for communal grazing and begrudged its use for crops ....
In a sense, the Elgeyo who took up farming on the plateau proved almost excessively responsive to new opportunities. Thus when the settlement and purchase of European farms became possible, some 900 to 1000 Elgeyo farmers abandoned their farms to take up allotments on settlement schemes or to buy, individually or possibly with others, European farms on their own initiative in 1962 and 1963. They had hardly exhausted the production possibilities of their existing farms before they were ready to "graduate" to new opportunities.

Tanzania

Anthony et al. (1979, p. 185) analyzed the farming systems practiced in Geita District, a part of Sukumaland, near the south shore of Lake Victoria in northern Tanzania, that receives a mean rainfall of about 940 mm/year.

The last thirty years have seen the complete transformation of what is now Geita District from tsetse-fly infested bush and miombo woodland, with a sparse population largely confined to the Lake Victoria littoral, to a major cash-crop and food-producing area. With the removal of tsetse fly and the provision of water supplies for human and livestock needs, immigrants flocked from the crowded areas east of Smith Sound. The population increased about five times from the mid-1930s to the mid-1960s and was settled in individual farmsteads throughout the district. By 1967 Geita was an important cotton producing area and exported substantial quantities of cassava to the central areas of Sukumaland.

In the period before independence, government preoccupation with soil deterioration in central Sukumaland led to emphasis on soil-conservation measures and the promotion of cassava and sweet potato cultivation as famine reserve crops. Farmers abandoned these imposed soil-conservation practices with independence, but they continued to observe the compulsory cotton uprooting date, although imperfectly.

Efforts to secure adoption of soil conservation measures by farmers have thus made little impact, but the other achievements of the colonial period were considerable, not the least of which was the promotion of new crops. The ready acceptance of cotton as a cash crop owes much to the work of the plant breeders at Ukiriguru [research station], who produced varieties with resistance to jassid and bacterial blight. This work, important under any circumstance, has special significance at an early stage of development when the small farmer is least able to bear risks.

The agricultural achievements of Geita District in the 1960s were impressive, and cotton production increased by about 60 percent between 1964 and 1967 largely through increased acreage. Some farmers, however, derived most of their cash income from cassava despite the pressure on them to produce more cotton. The trade in cassava was handled by small merchants, who appeared to be more efficient than the cooperative society.

Future increases in cotton production will have to be obtained largely through increases in yields per acre. Individual farmers are already short of suitable land, but there is considerable scope for increasing productivity per acre through early sowing, the use of insecticides and fertilizers, and general observance of the closed season. Adoption of higher yielding practices was limited by an inadequate extension staff and unavailability of modern inputs.

The general acceptance of early sowing has been limited by farm labor bottlenecks. Poor feeder roads make it difficult to open cotton markets before the end of the rains, so that farmers who sow early must store their harvested crop until the market opens.

At present, the economy of Geita District is mainly dependent on cotton production, but with cassava locally important as a source of cash income. Geita in 1967 was ripe for change. The standard of traditional farming was good and Geita farmers constituted a hardworking rural community.

Detailed studies of farm incomes indicated that there were large income differences between so called "progressive" and neighbouring farmers in the survey area. The "progressive" farmers obtained both gross and net incomes 2.5 times greater than their neighbours, and the differences in production per hectare were nearly as large (Anthony et al. 1979, p. 174). They found a strong positive correlation between the efficiency ratings of these "progressive" farmers and modernization scores that measure social, economic, and technical aspects of farmers' behaviour.

Synthesis

The subhumid savanna zone has the largest potential for cereal production in the savanna. The FAO Agro-Ecological Zones Project (FAO 1978, p. 113), suggests that the regions with growing periods of about 150–210 days are most suitable for sorghum, and those with about 150–240 days for maize, and that these fit well into this zone, with some overlap into the humid zone. In West Africa, this corresponds with the northern guinea savanna, which is the principal zone in which maize is spreading actively, mainly replacing sorghum. It appears that this fundamental change in the traditional farming system is occurring for about eight reasons.

- Small plots of maize have been grown for a considerable time, mainly confined to the relatively fertile areas close to the houses or sometimes mixed with other cereals.
- Early maize varieties provide the first staple food after the "hungry gap," in the form of fresh cobs.
- In areas with relatively fertile soils, or where manure is available, farmers have found that maize has a higher yield potential than sorghum.
- Maize responds well to phosphate and nitrogen fertilizers, particularly where sufficient OM is also made available.
- Development projects often provide a "package" of improved maize seed and fertilizer on credit, which has proved popular with farmers.
- Some governments have attempted to establish attractive minimum prices for maize, which give strong incentives to farmers to produce the crop.
- Sorghum, millet, and rice are particularly susceptible to bird damage, which can destroy the crop if it is not guarded. Early sorghum varieties, when planted early, may mature during the rains and develop grain moulds that reduce quality. Maize is less susceptible to these problems.
- Many sorghum varieties, particularly the red- or brown-grained bird-resistant types, contain tannins in the seed coat, which must be removed during processing. Some varieties of dry maize may be easier to process.

Pearl millet is also grown in this zone, particularly on the lighter soils, and often mixed with sorghum or maize. Rice-growing appears to be increasing wherever water is available. Other important crops include cowpeas and groundnuts, often grown mixed with the cereals, and cotton. Sweet potato and cassava seem to be spreading into the zone.

Many of the soils in the zone are relatively infertile alfisols, and there are large areas of shallow soils over iron pans or ironstone gravel. Under heavy population pressure, soil fertility declines rapidly and severe erosion can take place where bare soils are exposed by overcropping or overgrazing.

Livestock are important throughout the zone, and it appears that many farmers own about two to six head of cattle. In general, livestock are grazed on communal grazing land, although they may graze the stubbles as well as seasonal swampy areas in the dry season. Cattle are widely used for plowing, and sometimes for carting, in spite of trypanosomiasis problems in some areas. Donkeys and horses are spreading in West Africa for shallow cultivations, planting groundnuts, and carting. A few sheep or goats, or both, and chickens are also often kept.

Certain trees, such as the indigenous shea butternut (*Butyrospermum* spp.) and the introduced mango, are supplementary sources of food in this zone. Shea butternuts are carefully protected by farmers, but are not usually planted, whereas mangoes are planted.

Chapter 8: Humid savanna zone

Starting from West Africa, the humid savanna zone (Fig. 22) includes Guinea Bissau, much of Guinea, part of southern Mali, Côte d'Ivoire, Ghana, Togo, Benin, a large part of central Nigeria, Cameroon, most of the Central African Republic, a small section of southwest Sudan, most of Uganda, parts of the Kenyan highlands, most of Rwanda, Burundi, parts of western and southeastern Tanzania, and part of southern Zaire.

Although the soils of this zone are varied, there are large areas classified as ultisols on the West African coast and in Burundi, Rwanda, Uganda, and eastern Zaire, alfisols in much of Benin, Côte d'Ivoire, Ghana, Nigeria, Tanzania, and Togo, and oxisols in Cameroon, Central African Republic, and Zaire.

The natural climax vegetation of most of the zone would be light forest, with some open woodland in the drier parts and on the poorer soils, but most of the forest has been converted into derived savanna by human activities. This is a transition zone between savanna and forest, and between a unimodal rainfall distribution in about 190–200 days in the savanna part and a bimodal distribution in two rainy seasons each of 2–4 months, totaling 210–230 days, with two dry seasons, one normally longer than the other, in the area derived from forest. Parts of the zone, particularly where soils are light or shallow, can sometimes be difficult for annual crop production because, although two crops per year can sometimes be grown, there may not be sufficient rain in either season to produce an optimum crop. In general, however, the zone is well suited to perennial crops such as coffee, citrus, and bananas and to pasture, although livestock are limited because tsetse is widespread in the zone.

In West Africa, the zone is the main location of the "yam belt." This is the area extending from the Côte d'Ivoire through Ghana, Togo, and Benin into Nigeria and part of Cameroon, where yams have long been a traditional staple food.

Côte d'Ivoire

De Wilde (1967, p. 396) has described the yam-growing practices in the region of Bouaké, Côte d'Ivoire.
Yams are the most characteristic and basic food crop of the Baoule people. It is the crop that requires most of the farmers' time, occupies over half the cultivated land and is the starting point for rotations and mixed cropping. The Baoule have acquired a highly

developed technique for its cultivation. Proper selection of variety (early or late) and appropriate planting densities (9000 plants per hectare) enable them to secure very high yields estimated at more than 10 tons per hectare.

Yams are usually planted as the first crop in the rotation, after about 6 years fallow. They are planted on mounds and are nearly always grown mixed with maize, cassava, and cotton. Rice is also widely grown in Côte d'Ivoire, both as an upland and as a swamp crop. A wide variety of other crops including plantains (starchy bananas), cocoyams, groundnuts, okra, cucurbits, and peppers are also grown. Cotton production has increased in recent years, but robusta coffee is the principal cash crop, particularly in the areas derived from forest. The average area under cultivation for a family of 6–7 people with 3 ME ranged from about 1.15 to 2 ha or more including about 0.8 ha yams, 0.36 ha rice, and 0.8 ha coffee.

One of the characteristics of the Côte d'Ivoire is the large influx of migrant labour, mainly from Burkina Faso, but also from Mali, who work on the coffee and other farms often on a seasonal basis. In 1963, farmers paid out an average of some CFA 1300/year (US $5) for paid labour.

The program of "animation rurale," which was developed during the 1960s in the Côte d'Ivoire, deserves a mention here. This program was the responsibility of the Compagnie internationale de développement rurale (CIDR), one of the French organizations that play an important role in nearly all francophone countries. The "animateurs ruraux" were farmers who were chosen from the villages and given short periods of training every month at the Centres de formation d'animateurs ruraux (CFAR) to return to their villages and work with farmers doing simple, unpaid, applied research and extension. This program seemed to achieve considerable success, but like many such programs, its success appears to have led to its downfall, and the economic and political consciousness that was aroused was considered a threat.

Nigeria

Alade and Olugbo are two villages in the 1250- to 1500-mm cocoa belt of southwestern Nigeria whose farming systems were described by Upton (1967). In Alade, on average, 1.9 ha of the tree crop land in each farm was under cocoa, 0.34 ha under coffee, and oil palm, plantain, kola, citrus, and a few rubber trees were also present (Table 16). In Olugbo, half of the tree crop land was under cocoa, there was very little coffee, but oil palm, plantain, kola, and citrus were also found. Yams were the most important annual crop in the first year after fallow in both villages, intercropped with maize and other crops. In the second and subsequent years, maize or cassava, or both, and cocoyams and other crops would be grown. Olugbo also grew some rice in pure stand. Most farmers kept a few livestock on a casual basis.

Table 16. Average farm and family sizes in Alade and Olugbo villages, Nigeria, 1964.

	Alade	Olugbo

Total area per farm (ha)	7.72	7.06
Annually cropped	1.09	1.40
Under fallow	3.89	4.01
Under tree crops	2.74	1.66
Arable plots		
Average number	1.9	2.5
Average size (ha)	0.58	0.56
Average number in family	8.9	6.4
Average farm area per person (ha)	0.87	1.1
Average annually cropped area per person (ha)	0.06	0.09
Average tree crop area per person (ha)	0.3	0.26
Source: Adapted from Upton (1967).		

In both villages, the men worked for an average of 31 hours on their farms each week year round, increasing to 45 hours in the 5 busiest weeks. The women worked for 12–23 hours increasing to 25–35 hours in the busy period. In Alade, more labour was hired, working an average of 35 hours but increasing to 102 hours/week in the busy period. In Olugbo, there was little hiring except in the peak period when hired labour worked 18 hours/week. About one-third of the men had secondary occupations, and about one-third of the women were involved in traditional crafts or trading. Table 17 shows gross margins and incomes per farm.

Table 17. Gross margins and farm incomes (US$), Alade and Olugbo villages, Nigeria, 1964.

	Alade	Olugbo
Income		
Arable gross margin	143.5	164.9
Trees	361.0	202.8
Livestock	21.1	16.1
Total	**525.6**	**383.8**
Hired labour and fixed costs	60.7	17.0
Net farm income	**464.9**	**366.8**
Income from other sources	27.6	21.6
Total family income	**492.5**	**388.4**
Homegrown food consumption	133.4	106.6
Total cash income	**359.1**	**281.8**

Source: Adapted from Upton (1967, tables 2.26 and 2.28).

Most adult children had left the villages and found other occupations. However, about half the households included other relatives. Although these two villages seemed similar in many respects, in one village land was not sold, whereas about one-quarter of the farmers in the other village thought it right to sell land.

In the derived savanna area of southwest Nigeria, Atteh (1980) studied 120 farms in four villages in Kabba Division, Kwara State. The rainfall in this area averages about 1250 mm/year. Atteh was mainly interested in farmers' changing perceptions of their socioeconomic and physical environment and in the reasons they have for their strategies and techniques. Although he did not give many details of the farming systems, he did report the average cropped areas (Table 18).

Table 18. Average areas (ha) per farm under crops in the four villages in Kabba Division, Nigeria.

Village	Tree crops	Annual cultivated food plots	Total
Takete Ide	0.28	1.6	1.88
Iya and Aiyegomie	0.95	1.4	2.35
Olle	1.7	0.9	2.6
Eiuku	0.35	2.4	2.75

Source: Atteh (1980).

Land tenure was still the traditional communal system in which land was owned by village clans tracing their ancestry to a common individual who was usually a powerful warlord in the past. People from one village could not claim land in another village, but they could "beg" or rent land at a nominal annual rental of US $1–2 for a plot. People from outside the general area would find land rental more difficult.

Three broad types of land were recognized. Loamy savanna plains or uplands, forest land suitable for tree crops, and pockets of heavier clay soils in valley bottoms. The savanna land was not limited except in Olle village, but the other two types were. When searching for a new savanna plot in the bush-fallow land for annual cropping, farmers judged fertility and soil type by observing specific trees and grasses, by examining worm casts, and looking at the soil profile on the roots of fallen trees. A plot was cleared, burned, and cropped for 4–5 years, then left under bush fallow for 6–29 years depending on soil fertility, land availability, and other considerations.

Savanna plots were about 1–10 km from the village where everyone lived. Swamp and tree-crop land could be nearer the village, but swamp land was only suitable for yams, soybeans, rice, sugarcane, and some vegetables, which took a lot of labour. Farmers with savanna land remote from the village usually used bicycles to get there.

Farmers planted 3–13 varieties of yam on heaps, according to maturity length, cooking suitability, storability, and other criteria. Some varieties were grown specifically for sale. Similarly, many varieties of cassava, grain crops, beans, vegetables, and other crops had been tried and the most suitable selected. These were usually intercropped with yams or tree crops.

Labour was the main input and limiting factor to increased production, particularly in the peak season from May to October. Most households were nuclear with a male head, his wives and children, and relatives' children. Most of the children went to school and moved to town when they left school. Men did most of the clearing, hoeing, and weeding, with help from their wives for planting, harvesting, crop transport, processing, and marketing. About half the farmers were members of a working group that would work on each others' farms in turn, particularly during peak labour times such as heaping for yams. Some of these groups had hired a tractor to plow and ridge a joint farm on which they planted a cereal or bean crop in pure stand. Most farmers hired some labour, but because of its high cost (US $5–8/day) only for an average of 3–7 working days. Most farmers used a little fertilizer, but few other inputs except pesticides for coffee and cocoa.

Yams were the main staple foods, followed by *amala* (a mixture of sorghum flour with yam or cassava paste) or cassava. The staples were eaten with a vegetable sauce that might also include some meat or fish, pepper, palm oil, fermented locust bean, salt, and so on. It was difficult to store enough yams to last throughout the year, so by April–May yams and most other staples might be exhausted, leading to a difficult period until early maturing maize and yam became available in mid-June. Also, most farmers sold more food than they had previously, because of shortage of cash, especially for school fees. Many farmers also provided gifts of food for urban relatives, and might receive in return some gifts of cash or urban goods.

Atteh gives an interesting description of the changes occurring in the villages. For example, in Olle in the 1950s, farmers introduced first cocoa, then coffee, concentrating on these to the extent of buying much of their food. This policy brought prosperity for some years, but the slump in coffee and cocoa prices in the 1960s, followed by a grasshopper attack on the coffee, brought disaster that necessitated government food aid. This experience, together with rising food prices, caused the farmers to increase their food production and to start selling some food crops. By 1978, rising coffee prices were reviving some farmers' interest in the crop, but others felt it wiser and more profitable to concentrate mainly on food crops.

The Ilorin–Kabba road was tarred in 1974–78 leading to a dramatic increase in traffic from 2–4 vehicles/day to as many as 200. Many villages improved their own feeder roads so that taxis and pickups could reach the villages. Prices for foodstuffs rose sharply, giving an incentive to farmers to sell more, mainly to traders visiting the farms. The women sold smaller quantities in village markets, and kept their husbands informed of price changes. Farmers were well aware that traders made an 80–100% markup on prices when selling in cities in the south, but showed a realistic knowledge of transport costs and the difficulties of direct selling. Most farmers had worked on cocoa plantations further south in the 1950s or 1960s, earning money to get married, and 24% had been apprenticed to learn a trade.

Whereas in the past, family and farm size, number of cattle, or folk knowledge was the means of achieving recognition and respect, increasing contacts with towns had made farmers aware of higher standards of living there, to which they aspired. By 1978, formal education, modern houses, and goods such as cars, radios, watches, and so forth were status indicators. The young who went to the city returned at Christmas with these indicators of success. They reinforced the message of the radio and such officials as extension workers that the "educated" were progressive and rich and those who farmed were illiterate and poor. Farmers had absorbed this view of themselves. Their spending priorities were school fees to get their children educated so they could leave the farm and get a job in town, followed by building a better house, and, for some, saving to invest in a nonfarm business. There was little investment in the farms, except that cattle were purchased as a "bank on the hoof."

While Atteh emphasized the polarity that villagers saw between their own poverty and urban prosperity, he also stressed the constant interaction between villagers and townspeople. Parents visited urbanized children, children returned for the holidays, townsmen looked to the village for a spouse, often built a house there, helped in communal improvements, and planned to retire and die there.

Uganda

East Africa is one of the world's largest banana-producing areas, with an estimated production of some 18 million t of fruit/year, equivalent to about 25% of world output. Uganda alone is estimated to produce 12.3% of the world total (Karamura 1991). Although accurate data are scarce, it is clear that bananas are the most extensively grown foodcrop in Uganda, and are reported to cover over 1.2 million ha. It is estimated that the crop is grown by 75% of the country's farmers on 40% of the total arable land (Rubaihayo and Gold 1993). Although it is not known for how long bananas have been grown in Uganda, they have been there for several hundred years and are the most important food staple for many of its people. The highland bananas of East Africa are a unique set of cultivars that have been selected by farmers under local growing conditions. They are mainly cooking bananas that are steamed for eating. Dessert and roasting types are also grown, and some cultivars are used for local beer production.

Although bananas are the dominant crop in many of the farming systems of Uganda, they are usually grown in complex mixtures with up to 15 other crops. In the more fertile areas near Lake Victoria, a major component of the farming system is robusta coffee, which is an important source of cash, and the country's largest foreign exchange earner. At higher altitudes, from about 1500 to 2000 m on Mount Elgon in the east and in the west and southwest, arabica coffee is grown mixed with bananas. Other important crops include sweet potato, cassava, maize, and *Phaseolus* beans. Although the average household growing bananas has 11 members and 3.5 ha under cultivation, of which 44% or 1.5 ha is under bananas, usually mixed with other crops, in recent years, increasing land pressure, particularly in the heavily populated areas around Kampala, has led to a decrease in farm size, sometimes to less than 1 ha, and to declining production and yields.

A rapid rural appraisal at 25 randomly selected villages throughout the banana-growing areas in 1992 indicated that average banana yield had dropped from 8.4 t/ha in 1970 to 5.6 t/ha. In 18 of the villages, farmers reported a decline in soil fertility, and in 11 villages cassava had taken over from bananas as the most important staple. Some farmers had abandoned banana-growing completely. Farmers were generally aware that fallowing or soil amendments such as mulch or manure could help to improve soil fertility, but few had the land or labour resources to undertake these. As a result, the main producing area has shifted to the western part of the country where fertile soils are still available, and some 75% of the large urban markets of Kampala, Entebbe, and Jinja are now supplied from that area. Additional factors in the decline in yields are diseases, such as black sigatoka and fusarium wilt (Panama disease), and nematode and weevil (borer) pests (Rubaihayo and Gold 1993). Some cattle are kept, but are often herded by employed herdsmen. An interesting recent development has been the spread of modern dairy farms. Goats are also common.

Richards et al. (1973) have described the development of commercial coffee farming in Buganda (the largest province and the centre of the banana and coffee-growing area north of Lake Victoria) in the 1950s and 1960s. Stimulated by high prices, which rose from about US $0.04/kg in 1938 to US $0.33/kg in 1954, the Baganda farmers increased their plantings of robusta coffee from about 24 000 ha in 1944 to over 120 000 ha in 1956, and over 280 000 ha by 1966 (Richards et al. 1973, p. 31) making Uganda the world's fourth or fifth largest coffee-producing country at that time.

Because Buganda had had an individual system of land tenure for much of the land since the early years of the century, some farmers were able to inherit or buy large areas of land. For example, one farmer was found to own nearly 2000 ha of land, and he was still hoping to buy more. However, although land areas actually farmed varied widely, it was found that farms averaged 0.46 ha of food crops per resident, and this value did not vary much (from 0.1 to 1.4 ha). The average area under cultivation per farm was 1.5 ha, and the average holding size in Buganda in 1963 was 2.6 ha, with 4.4 people/family. Areas planted with coffee were usually less than 4 ha/farm, but a few farmers had up to 40 ha or more. Average yields of wet coffee cherry on 30 surveyed farms were 2900 kg/ha, but there were wide variations in yields from about 300 to over 7000 kg/ha. The profit margins per hectare and per farm varied in proportion.

Much of the work on the Buganda coffee plantations was done by immigrant labour that came from Burundi, Kenya, Rwanda, Tanzania, and the poorer parts of Uganda to find work. In 1963, over 138 000 were employed on coffee weeding and nearly 58 000 on coffee picking. For a long time, the rate of pay was UGS 1.00 (Ugandan shilling, about US $0.14) for a 1-day "task," which was equivalent to weeding about 220 m^2. Many of these "porters" eventually acquired a plot of land and settled permanently (Richards et al. 1973, p. 185).

Kenya

The rainfall in the Kenyan highlands varies considerably with altitude, and because temperatures and evapotranspiration rates are reduced with increasing altitude, a given quantity of rainfall may be more effective than at a lower altitude. Substantial areas receive between 1200–1500 mm, and soils of volcanic origin are widespread. For example, much of Nyeri District, to the north of Nairobi, comes into the humid zone. The area populated by the Kikuyu people, who live mainly in Nyeri, Kiambu, and Muranga districts, is one of the most densely settled regions in Africa. By 1962, the population density was already 315/km^2. Kenya's population increase rate — over 4% per year, at that time the highest in the world — means that the population will double in about 17 years. However, some people are moving out of the most heavily populated areas.

The following description of Nyeri District is taken from de Wilde (1967, p. 33). The altitude varies from about 1200 m in the southeast, to roughly 2300 m on the slopes of the Aberdare Mountains to the west, and the rainfall varies from about 900 mm in the southeast to about 1800 mm in the southwest. However, much of the District lies between about 1500 and 2000 m altitude, and receives about 1000–1500 mm rainfall in the two rainy seasons — the "long rains" in March–May, and the "short rains" in November–December. Most of this area is described as the kikuyu grass ecological zone, and has a high potential for crop production. The principal staple food crops are maize and beans, usually grown mixed. Both sweet and *Solanum* potatoes are also widespread, with a wide range of other crops including vegetables and fruit. The main cash crop is arabica coffee, but tea and pyrethrum are also grown in the higher areas.

In the late 1950s and early 1960s, one of the most remarkable revolutions in the history of African agriculture took place in some of the highland areas of Kenya. This came about as a result of the Swynnerton Plan (Swynnerton 1954) that set out to reorganize and increase output and profitability from the African farming area. By the mid-1950s, increasing pressure on the land had led to soil exhaustion, erosion, fragmentation, declining crop production, and often poverty and hunger in most of the heavily populated areas in Kenya. Many of the men (estimated at 29.4% in 1962) had left their home areas to work either in Nairobi or in large-scale farming areas. On these farms, they gained considerable experience of modern farming methods and potentials.

From 1954, the Government of Kenya began to implement the Swynnerton Plan for the development of smallholding agriculture. This Plan placed a strong emphasis on expanding cash-crop production under careful controls to ensure good land and crop management, high yields, quality, and profitability. In addition to the emphasis on cash crops, a radical program of land consolidation, registration, and planning farm layouts was put into effect.

Once the farmers in an area had agreed to consolidate and register their holdings, accept a new farm layout, bench-terraced 0.2 ha of land, and dug holes for coffee planting, they could obtain coffee seedlings. These were manured, mulched, pruned, and sprayed against pests under the supervision of the coffee instructors, and high and profitable yields were obtained. Initial costs of coffee planting were paid off in 4 years, and the surplus of current income over cash expenditures on mature coffee grown by a selected sample of farmers averaged KE £420/ha (about US $1260) in 1962/63, and KE £408/ha (about US $1200) in 1963/64, respectively. This was equivalent to a return of KES 4.54 (about US $0.65) and KES 4.16 (about US $0.60) respectively per hour of family labour devoted to coffee. The farmers obviously considered the incentive to grow coffee very attractive at this time, as the number of growers increased from 7886 in 1960 to 22 512 in 1963, and continued rapid expansion took place. A similar expansion occurred in tea and pyrethrum production in areas suited to those crops.

It is interesting to note that many farmers were willing to put substantial labour and cash outlays into planting these crops knowing little return would be obtained for 3 or 4 years, in the expectation of eventual profits. De Wilde (1967, p. 49) continued

In many respects the most remarkable phenomenon has been the rapid development of dairying with cattle of European breeds, principally Guernsey and Jersey.
Farmers who had had their holdings consolidated and planned and who had fenced paddocks were assisted to purchase "grade" cattle (these are crossbred local zebu with Friesian, Guernsey, Jersey, and other breeds) and to manage them for intensive milk production. The milk was marketed through cooperative societies, which increased their sales 10-fold between 1960 and 1964 when over 5 million L were marketed, mainly to Nairobi. In addition to the regular cash income received, the rapid expansion of production indicated that the farmers found dairying highly profitable. One study indicated a net cash income of US $55–64/cow per year. They were also able to use some of the milk (probably about one-third) for home consumption. These highly intensive farms, despite their small size, were also labour-intensive, and many of them used substantial amounts of hired labour.

By the early 1990s, farmers were encountering increasing problems of declining soil fertility and soil erosion. Cheatle and Njoroge (1993) have described the rapid decline in OM content in the upper soil layers with adverse effects on chemical fertility and physical properties. Extension recommendations have been mainly to use more chemical fertilizers, but increased costs have often put these out of reach of smallholders. Among other initiatives to try to cope with this situation, Njoroge, a Kenyan agronomist, started the Kenya Institute of Organic Farming (KIOF) in 1987 with support from Misereor (a Catholic Church aid agency) and later from IDRC and other donors, with the aim of promoting more productive and sustainable smallholder farming systems through organic farming.

KIOF has stressed intensification of crop production, particularly through composting, double digging, and water harvesting in addition to other techniques. From the outset, the approach has been only to respond to requests from self-help groups, which may or may not be church related. A promoter works with each group on a member's farm for 1 week, training the group in practical organic-farming techniques. The promoter then follows up members of the group on their own farms for 3 months, then going on to work with another group. Farmers' visits to more advanced organic farmers in neighbouring areas have also been organized, and these approaches have proved highly effective in popularizing organic farming. Since 1986, over 200 farmers' groups with about 5000 members have been trained in organic farming. An adoption-rate survey shows that, although adoption rates vary for the different practices recommended, over 85% of highland farmers adopted composting and over 70% double digging, despite these techniques being labour intensive. Some smallholders each made up to 24 t of compost annually. Maize yield records from a limited sample of farmers indicated substantial yield increases from composting. The farmers adapt the techniques to their own needs and devise their own experiments on new techniques.

Tanzania

The rainfall on the two islands of Ukerewe and Ukara, which lie in Lake Victoria just off Sukumaland, varies from about 1170 to 1600 mm, which puts them mainly in the humid zone. The farming systems practiced by the people living on these islands show interesting parallels and differences with those of the Sukuma.

In 1967, the population of Ukerewe Island was 88 000 on an area of 554 km^2, giving an average density of 159/km^2. As the population was then increasing at 2.2% per year, the density would have nearly doubled to about 320/km^2 by 1995 if no outmigration had taken place. The farming system consisted mainly of cassava and cotton, with about 1.2 ha of cassava and 0.6 ha of cotton per family that averaged 9.2 people. Some farmers also grew rice, sweet potato, and perhaps a little sorghum, maize, or bananas. Some of the fallow land was manured by tethering the three or four head of cattle owned by each farmer. Fertilizer trials indicated only a limited response to chemical fertilizer. In general, cassava was cultivated continuously on the hill sands, but was sometimes planted after cotton. Cotton tended to be planted on the hardpan soils.

Although population pressure on the land is increasing on Ukerewe, it has been high (500 people/km^2) on Ukara for more than 100 years (Ruthenberg 1980, p. 158). The Wakara have evolved their own intensive land-use system in response to the land shortage. Each family practices intensive cultivation on about 1 ha of land, growing pearl millet intercropped with legumes, applying manure each year in the main rains, followed by groundnuts in the second rains in the second year, and sorghum or cassava after millet in the third year. Also, small plots of rice are cultivated in the valley bottoms. Manure production is of great importance, and this requires careful production and conservation of fodder. Animals are housed at night and litter is provided for them. The Wakara work harder than neighbouring farmers, but are poorer, with a net income of only US $40/ME in 1964. If they emigrate to Sukumaland, they usually adopt the local fallow-farming system and abandon their own intensive system (Ruthenberg 1980, p. 160).

Zaire

Describing the farming system in the Kwango–Kwilu area of central Zaire, Fresco (1986) has taken an ecological systems approach to develop a framework that allows the integration of technical, biological, and socioeconomic factors that influence agricultural production. Although this area is on the margin of the humid savanna as defined here, with 1500–1600 mm annual rainfall from September to May, and a dry season from June to August, much of the area consists of treeless grassland savanna. This is a rolling table land gently sloping from 1100 m altitude in the southwest to 350 m in the north. This agroecological zone, covering about two-thirds of the area, or 105 000 km², is named after the Kalahari sands that characterize many of the soils. These are very permeable with low OM and nutrient contents, which together with frequent burning probably account for the limited distribution of trees. The other agroecological zone is the Karoo, which consists of wide forested valleys in the central part, with slightly more fertile soils derived from Karoo formations.

The total area is 167 000 km² and the population was estimated at 2.2 million in 1976, increasing at 2.6% per year. The average population density in 1976 was 23 people/km², but this would have nearly doubled by 1994. Of the population, 80% was engaged in agriculture, but most of the agricultural work was done by women, because most men were working in the cities. The farming system is comparatively simple, with cassava by far the most important crop, still grown in a mainly shifting-cultivation system. Total cassava production in 1979 was estimated at over 6 million t from 479 000 ha. The next most important crop, maize, only produced some 236 000 t. Small amounts of groundnuts, pearl millet, bambara groundnuts, sweet potato, yams (various species), squash (various species), and a few bananas and plantains are also grown, often intercropped in the cassava. Upland rice is mainly grown in cleared patches in the forested valleys of the Karoo zone. Oil palm is indigenous, and is estimated to cover some 140 000 ha.

Such data as are available from the Kwilu indicate that, in 1970, the total number of farmers was about 190 000, increasing to 250 000 in 1980, 95% of whom cultivated less than 3 ha, with an average cultivated area of 1.4 ha. Because the average number of people per farm was 6.4, this gave an average cultivated area per person of 0.22 ha. Of the total estimated production of dried cassava of 1.642 million t, nearly 1.0 million t was marketed, mainly to Kinshasha and other towns, and the remainder was consumed on the farms. Equivalent data from the Kwango, which has a much smaller cultivated area, do not appear to be available. Annual cassava consumption per person averaged 180 kg of dried cassava, or about 540 kg of fresh roots, providing an estimated 60–70% of total calory intake. It is eaten as a porridge, which is sometimes mixed with small quantities of maize or millet flour. Otherwise, maize is only consumed on the cob. It is thought that cassava, including cassava leaves, which are also eaten, only supplies about 20% of dietary requirements for protein. Because other sources of protein are very limited, protein deficiency is widespread.

Although there are some doubts about the accuracy of the values for average annual farm-household cash income and expenditures (Table 19), they do give some indication of the very low cash incomes and expenditures in this farming system. The main staple crop consumed was cassava, which was valued at about US $144/t. Even adding the value of the dry cassava consumed (180 kg/person per year) only brought the income plus consumption totals to US $65 and US $78 in the Kalahari and Karoo zones respectively (the values of other home-grown crops consumed could not be estimated, but would only have been a few dollars).

Table 19. Estimated average annual farm household cash income and expenditures (US$), Zaire, 1980/81.				
Source	Kalahari Zone		Karroo Zone	
	Household	Per-capita income	Household	Per-capita income
Income				
Cassava	91	14	157	25
Other foods	12	2	55	9
Livestock	1	0	19	3
Wages and remittances	55	9	38	6
Crafts	48	8	37	6
Other (fishing, hunting, palm wine)	37	6	21	3
Total cash income	**244**	**39**	**327**	**52**
Value of cassava consumed	166	26	166	26
Expenditures				
Agricultural inputs	3	0	24	4
Food	62	10	107	17
Clothing	33	5	75	12
Domestic (kerosene, soap, etc)	42	7	54	8
Medical	11	2	17	3
School fees	18	3	23	4
Taxes	4	1	6	1
Social (gifts, travel, etc.)	4	1	8	1
Total expenditures	**177**	**29**	**314**	**50**
Balance (income over expenditure)	**67**	**10**	**13**	**2**
Source: Derived from Fresco (1986, tables 6.1 and 6.2).				

Although accurate yield values are lacking, Fresco (1986, p. 187) considers that

Circumstantial evidence would suggest that average cassava yields in the Kwango–Kwilu have been declining since the mid-1950s. The reasons for this decline can be attributed to factors at all levels in the hierarchy of systems.... These are summarized in Figure [23]. ... At the regional level, a growing demand for cassava and the relative decline of agricultural prices lead to early harvesting of the crop. Increasing population densities cause fallows to shorten, resulting in changes in fallow vegetation and the increase of grass fallows.... At the farming systems level, production has expanded onto the plateaus .... Greater demands are put on female labour due to the absence of men from the agricultural sector and possibly due to the increase in area .... At the crop and cropping

systems level, changes in agricultural practices are apparent. They result from the interaction of declining soil fertility, shorter fallows, shifts in the agricultural calendar and womens' increased work loads. ... The overall effect seems to be a tendency towards the monocropping of cassava. It is unclear to what extent pests and diseases are contributing to the yield decline .... Thus, declining or stagnating cassava yields must be seen as a symptom of a wider problem, the *breakdown of the shifting cultivation system* [original italics] in the Kwango Kwilu.
This conclusion allows a return to the assumptions on the nature of the African crisis .... Declining yields are indeed a symptom of the crisis. The emergence of inframarginal land shortages makes it unlikely that the area under cassava can be substantially increased. At the same time, the recent increases in pest and disease incidence as well as the considerable amounts of nutrients exported from the area raise serious questions about the potential for maintaining yields even at the present low levels.

Synthesis

Because the humid savanna is a transition zone between a unimodal and a bimodal rainfall distribution, and between savanna and forest, it is well suited to a wide range of crops, both annual and perennial. In West Africa, the "yam belt" is mainly found in this zone, together with cassava, maize, sorghum, rice (both rainfed and swamp), groundnuts, plantains (starchy bananas), coffee, citrus, oil palm, and others. Because of widespread trypanosomiasis, cattle are less common in this zone than in the drier zones, but goats, sheep, and poultry are common.

In East Africa, where the rainfall distribution is mainly bimodal, bananas are an important staple food at the middle altitudes in Rwanda, northern Tanzania, and Uganda, together with sweet potato, cassava, maize, *Phaseolus* beans, and some swamp rice. Robusta coffee is the main cash crop, and some tea, sugarcane, and pineapple are also grown. Many different fruit trees are planted, including citrus, loquat, avocado, breadfruit, and jackfruit.

At the higher altitudes, maize is the dominant cereal, with *Phaseolus* beans, sweet and *Solanum* potatoes, bananas, arabica coffee, tea, pyrethrum, and a wide range of vegetables and other crops.

Although trypanosomiasis is present in some of the low and medium altitude parts of the zone in East Africa, it is less widespread than in West Africa, so cattle, sheep, and goats are widely distributed. The climate is excellent for pasture, so there has been an impressive development of highly productive small- as well as larger-scale dairy farms in the Kenyan highlands, with European and European-crossed dairy breeds, and dairying has extended somewhat into Uganda.

Although there can be problems with annual crop production in this zone, because neither rainy season can be relied upon to provide enough rain for a crop in some areas, the zone generally has a high potential for both crop and animal production, particularly at the higher altitudes and on the better soils. In West Africa, it does not yet appear to be too heavily populated in most areas, although populations are probably increasing rapidly, partly by in-migration. In East Africa, the highland areas in the zone are some of the most heavily populated regions in Africa. Although there have been some impressive developments of highly intensive farming systems, particularly in the Kenyan highlands, there appear to be dangers of holdings becoming subdivided and fragmented into uneconomically small areas that may not be sufficient to provide subsistence, let alone a reasonable income. Deterioration of soil fertility and erosion also pose a constant threat.

Part III — Conclusions

Chapter 9: Physical environment

This chapter contains a brief analysis of the environmental problems facing savanna Africa. The most important being land use, rainfall, and soils (see Chapter 2).

Land Use

The introduction indicated the huge size of sub-Saharan Africa (over 24 million km^2); the diversity of countries, peoples, economic, social, and political conditions; and the population explosion that is engulfing the continent.

In a detailed study of land-use practices and the carrying capacity of the land, Higgins et al. (1982) analyzed the areas and countries that are most at risk from excessive pressure of people and their livestock at existing low-input levels. They identified almost the whole of the arid and semi-arid savanna zones (see Chapters 5 and 6) and the adjoining semi-desert, together with other heavily populated areas including part of Angola, Botswana, Burundi, Eritrea, the highlands of Ethiopia, Kenya, Malawi, southern Mozambique, most of Nigeria, Rwanda, Tanzania, western Uganda, eastern Zaire, and southern Zimbabwe, as being particularly threatened (Fig. 24, shaded area).

The stresses built up in some of these areas have already caused famines, and in some measure have contributed to political instability and civil wars. There were indications that the carrying capacity of these areas could be increased, but only if higher levels of inputs, particularly manures and fertilizers, and other more productive farming practices, could be introduced.

It is not clear whether farming systems will change and intensify fast enough to keep pace with population growth and to allow reasonable standards of living in many of these areas.

In many areas, as population and livestock pressures increase the soils become more impoverished and growth of both crops and natural vegetation are reduced, exposing the bare soil to erosion. Farmers respond where possible by replacing the more valuable grain crops with crops such as cassava, which can produce a harvest on quite poor soils (see, for example, Fresco 1986). Eventually, crop yields may reach a fairly steady state at a relatively low level, which may provide subsistence for the inhabitants. Further losses of topsoil, particularly where the soils are shallow, may cause abandonment of cultivation altogether (Ruthenberg 1980, p. 11).

Land-use practices are of critical importance to the long-term future of all countries, yet they often seem almost totally neglected by many governments. Although governments may be overwhelmed by a multitude of problems, all needing attention at the same time, and they may have considerable difficulty in having much effect on rural life, their allocation of resources sometimes seems questionable. Instead of attempting to guard, conserve, and build up what is their main productive physical resource, the land, they sometimes almost seem to encourage its exploitation, either by unwise policies such as allowing large-scale mechanized land clearing or deforestation, or by almost total neglect of simple soil-conservation and improvement measures.

Although governments often pay lip service to increasing agricultural production, and employ large bureaucracies in their agricultural services, many of their policies and resource allocations usually seem mainly directed toward the needs of the wealthier section of the urban population, rather than the rural poor (see, for example, Carr 1982).

Rainfall

Uncertainty because of rainfall variability is one of the most difficult problems facing savanna farmers. Although farmers have developed various strategies for trying to cope with rainfall variation, for example those described by Collinson (1989), most of these strategies are uncertain at the least, and the risks of severe reductions in crop yields or crop failure are high if the rains are inadequate or poorly distributed.

Stewart (1989, p. 260), working in Kenya, Niger, and elsewhere, appears to have made an important contribution toward the prediction of "good" as against "poor" rainy seasons by correlating these with the date of onset of the rainy season. He found that when the rains started early in the season there was a strong statistical probability that sufficient rains would be received for normal crop growth, whereas when the rains started late, the average amount of rainfall and the length of the rainy season would be reduced by about one-third, often making it inadequate for a satisfactory crop. His concept of "response farming" would enable farmers to use this knowledge by adjusting their farming practices according to the date of onset of the rains. This concept is being widely tested around the world, and when it is known whether it is applicable in various areas, it should make a valuable contribution to savanna farming systems.

Obviously, a most important contribution to correcting soil moisture deficiencies and to tropical agriculture in general can be made by irrigation, which is relatively underdeveloped in Africa compared with Asia. Although there has been some development of irrigation in the Sudan and some other areas, there is enormous scope for increasing its extent using the ample supplies of fresh water in many parts of Africa. Because much has been written on this elsewhere, I have chosen not to cover it in detail here (but see, for example, World Bank 1986).

Soils

African soils are as varied as those in other parts of the world, but because many of them are derived from the ancient granitic rocks of the African shield over much of the continent their inherent fertility is low. Sanchez (1976, p. 73) estimated that alfisols and oxisols alone cover 1100 million ha or 55% of the total land area. Most of these soils are sandy with low CECs and limited nutrient contents, often shallow over ironstone gravel or plinthite, and subject to erosion.

Although soil OM contents can be quite high under natural vegetation or forest, they decline rapidly when the land is cleared and cultivated. Acid soils are widespread, and although some crops can tolerate certain levels of acidity, the growth and yields of many important crops are reduced. Many savanna countries have natural deposits of lime and phosphatic rock, but these deposits have been little used by smallholders.

As land pressure increases because of the growth of human and livestock populations, more and more land is denuded of its natural vegetation by cultivation, overgrazing, and the removal of trees. Eventually, some cultivators are forced onto hill slopes and other marginal lands. The increasing proportion of the land that is left bare and exposed to high-intensity rainfall is prone to erosion unless urgent counter-measures are taken.

The dangers of soil erosion are outlined in Chapter 2, and soil-conservation measures considered in the discussion of many of the farming systems in Part II. However, there is no doubt that the battle to conserve the soils of Africa is being lost. This is obvious to anyone flying over such countries as Ethiopia, where the severe scarring of hillsides and the muddy state of rivers and streams indicate the enormous losses of topsoil that are occurring. Yet Ethiopian farmers have developed their own simple soil-conservation methods. For example, after preparing the land for a crop with the traditional *ard* (a plow without a mouldboard), farmers will always finish the work with a few shallow furrows across the field, about 10–15 m apart, just off the contour, so that any runoff will run down these furrows and off the field instead of continuing on down the field.

However, the heavy population pressure in most of the highland areas forces people to cultivate any fallow land available, including progressively steeper hillsides. Also, the repeated cultivations necessary to prepare land for the staple grain, teff, during the early part of the rainy season mean that over-cultivated land is exposed to heavy rains, so the traditional contour furrows, although reasonably effective with a lower population density, do not prevent erosion.

It is well known that erosion is negligible under natural vegetation undisturbed by farmers or their domestic animals. In the areas with more favourable rainfall distribution — where perennial crops such as bananas, cocoa, coffee, tea, or fruit trees could be grown — provided a good leaf canopy was maintained over the soil, little erosion would take place, and farmers often developed their own methods of conserving rainfall with ditches and basins. Mulching in bananas and other crops was also an effective soil conservation method. Many farmers were also skilled in intercropping young perennial crops with other crops such as beans or groundnuts that reduced weed competition and covered the soil. They would also allow "soft" weeds, such as *Galensoga parviflora*, that did not compete strongly with the crops to grow during the rains, to be slashed and left as a mulch or dug in as a green manure during the dry season.

In many traditional shifting-cultivation systems, farmers have developed ways of keeping a cover on the soil for as long as possible, either with natural vegetation, weeds, or crops. Grain crops are often planted as early as possible after the start of the rains, after a rough digging or plowing, both to give the best possible chance of obtaining a good crop, and so that they would have grown enough to cover the soil before the heavy rains, which often come about the middle of the rainy season. Mixed cropping with fast-growing crops such as beans or cowpeas is also commonly practiced, and these not only give an early crop, but also help to cover the soil. With increasing pressure on the land, however, these methods often become less effective. This is particularly apparent on the larger continuously cultivated plots on the lighter soils, where soil OM is reduced, soil structure deteriorates, and crop growth is poor allowing unimpeded erosion to take place, especially on the steeper slopes.

In some countries, colonial governments tried to impose various soil conservation measures on the farmers, mainly in the form of contour grass strips, contour "bunds" (banks), and narrow- and broad-based terraces (Hudson 1981). These were often resented by the farmers, particularly where land was limited, and sometimes they were destroyed after independence. In Kenya, a Swedish-funded soil-conservation project first did a careful survey of indigenous soil-conservation methods, such as the *fanya juu* contour ditches, and then trained government extension workers in these methods. The extension workers were then able to train the farmers in the same methods, with good results in many areas (Eriksson et al. 1980).

Chapter 10: Farming systems

Agronomic and Livestock Aspects

African farming systems have evolved over many centuries in response to particular sets of environmental conditions, and they are constantly changing in response to changing circumstances.

In their struggle to sustain themselves and their families from the land, farmers have had to find out for themselves what works under widely varying rainfall and other conditions. The results have been the patterns of farming systems that have developed throughout the savanna, some of which I have described in Part II. Because these systems have to be adapted to the natural ecosystems in each particular area and, at the same time, provide the needs of the farmers and their families, they can be described as farmer-managed ecosystems.

Although these farming systems can be classified in many different ways (see, for example, Ruthenberg 1980), in view of the fundamental importance of natural environmental factors, particularly climate and soils, that give rise to the natural vegetation, I have used a bioclimatic classification here (Fig. 15). In this way, the savanna is divided into a number of zones based mainly on annual rainfall amount and distribution.

Although the divisions between the zones (see Table 4) are arbitrary and difficult to define in places, they do seem to fit reasonably closely to Phillips' original bioclimatic classification (Phillips 1959), the FAO classification based on length of growing seasons (FAO 1978), as well as the regional classifications developed for the various regions. They also appear to reflect real differences in the patterns of farming systems *between* the various zones, although inevitably the zones blend into one another. On the other hand, because the zones cover enormous areas, they obviously include considerable variations in the farming systems *within* the zones. These systems require further research both on a national and a regional basis.

As rural populations and livestock numbers increase, the whole question of intensification of agriculture becomes of critical importance. At some level of population density, the old shifting cultivation systems break down. In the Katsina area of northern Nigeria, Grove (1961) estimated that this breakdown took place at a density of about 58–77 people/km^2, but it will obviously vary greatly with the carrying capacity of the land, rainfall, and other factors in different areas. Allan and his colleagues (1965) made an important contribution to the methodology of measurement of this and other parameters, and Fresco (1986) has suggested an ecological approach. It is difficult to find research that follows up either of these approaches in detail in other locations.

Mixed Farming Systems

Mixed farming systems are those in which both crops and livestock are kept on the same farm, and each part of the system contributes in some measure to the other. Most African farms come into this category.

Crops

Traditional rainfed cropping systems throughout the arid and subarid zones are mainly based on pearl millet on the lighter sandy soils and sorghum on the heavier soils, often with cowpeas intercropped. Farmers plant a range of varieties of these crops for particular purposes and in different microecological habitats. They generally have strong reasons for their choices as their survival depends on them.

Increasing pressure of both population and livestock throughout these zones are causing severe stresses to the cropping systems. In some areas that have long been heavily populated, such as northern Nigeria, the permanent cultivation systems that enable continuous cropping have been described. Cash crops in the form of groundnuts (mainly in West Africa) and cotton are also grown in the subarid and subhumid zones, maize is replacing some of the sorghum, and rice is becoming more widely grown in swamps and irrigation schemes. Hungry rice and bambara groundnuts are still grown on some of the poorer soils. In the subhumid zone, a wide range of other crops, including sweet potato, cassava, sesame, pigeonpea, and many fruits and vegetables, are also cultivated, usually in mixtures. There is evidence that mixed cropping can increase both the net value of the production and the net return to labour.

In the humid zone, a much wider range of crops has become important, including rootcrops such as yam and cocoyam as well as sweet potato and cassava, and perennial crops including banana and plantain, cocoa, coffee, and at the higher altitudes in East Africa, tea and pyrethrum.

Livestock

Livestock throughout Africa are generally kept on an extensive basis, and herded on communal grazing areas. In addition to providing some meat, milk, and hides, they often seem to be valued mainly as a way of saving money or as an insurance policy — a "bank on the hoof." When livestock populations increase above the carrying capacity of the land, the result is overgrazing and destruction of the pastures. These pastures belong to everyone and yet no one is responsible for them. In the arid areas, this is a very difficult problem that is outside the scope of this book, but some farmers do their best to supplement dry-season grazing by the use of forage such as groundnut tops, cereal straw, and loppings from many trees such as *Faidherbia albida, Acacia* spp., and others.

Even in the more humid areas, there is little sign of more productive livestock systems developing except in some densely populated areas such as the Kenyan highlands where intensive dairying, often from stall-fed cows, is highly profitable and fits well into the system. There are also some larger fenced dairy farms in Kenya and Uganda that show the potential of these methods. As populations increase and communal grazing becomes scarce, it appears that there is a huge potential for more-intensive livestock production systems to develop, but these may require land tenure and other changes.

Manure

In some areas, such as the parts of northern Nigeria that have long been densely populated, the farmers who own livestock have developed their own methods of permanent agriculture by the use of manure, including latrine manure, compound sweepings, and cattle dung partly from their own cattle and partly from Fulani pastoralists who were paid to graze their cattle on the stubbles after harvest (Hill 1972). Little fertilizer was used and most of the manure was applied to the permanently cultivated fields around the house compound, whereas less was applied to the more distant fields. This is described as "ring culture."

In Mali, Toulmin (1983) reported the traditional system of digging wells to reward the nomads for corralling their cattle on the stubbles by watering the cattle, and it appears that this and similar systems may be widespread in the arid zone. Further south in Mali, farmers were originally encouraged to apply both manure and fertilizer on cotton, but this seemed to have almost died out earlier this century. However, some farmers in Gladie village have adopted this system and adapted it to their needs by applying manure and fertilizer to cotton followed by maize intercropped with millet, followed by sorghum and groundnuts, with very productive results.

Research in Sakoro village showed that although soil fertility had declined seriously so that 80% of households were not self-sufficient for food, a similar program of manure and fertilizer use on maize could have similar results, and this seems to be spreading. By breaking the poverty cycle, this gave them a wider range of choices and allowed the peoples' own creativity to emerge in tackling their own problems. This village had probably fairly recently reached the critical level of population density at which the shifting cultivation system broke down.

In Kenya, an already intensive farming system was found to be declining in soil fertility despite heavy fertilizer use; therefore increasing quantities of manure from stall-fed dairy animals and compost from crop residues and other materials were applied to the land. This resulted in higher production.

In Tanzania, farmers on Ukara Island had long ago established their own intensive systems with manure from stall-fed animals applied to intensively grown crops. However, when these farmers migrated to less heavily populated Sukumaland, they usually abandoned their intensive methods.

In Chibi, Zimbabwe, when increasing population pressure led to reductions in fallow and grazing areas, some farmers' cattle numbers and manure production were also limited, undermining these farmers' strategies to maintain soil fertility. As a result, the maize yields of cattle owners were double those of nonowners. Most farmers considered that the unreliability of the rains in this area made the use of chemical fertilizers too risky.

Although these examples indicate that the value of manure is widely known, its use is comparatively rare in Africa. Only in those areas where the shifting cultivation system has broken down because of population pressure will farmers normally start using manure systematically, and even then there may be a long lag time, and they may be forced to give up if they cannot keep sufficient livestock.

Chemical Fertilizers

There is some evidence that, on certain soil types, the combination of fairly small quantities of manure with small amounts of chemical fertilizers can have synergistic effects — apparently greater than either used alone — and this practice could save labour for heavy manuring and money for heavy fertilizer applications. This approach should be worth testing over wide areas, yet there appears to be little experimental evidence of its effects.

Fertilizer alone is generally little used throughout Africa, although there are exceptions, usually where a high-value crop is grown for sale at a fixed and often subsidized price, for example, maize in Kenya or Zimbabwe or groundnuts in Senegal. In general, farmers who are near subsistence level cannot afford to buy much fertilizer, and many of them may have never learned to use it.

Animal Traction

Most cultivation in Africa is still done with various types of hand-hoe. Only in Ethiopia has animal traction been widely practiced for thousands of years. Anthony et al. (1979, p. 140) suggest that, with the exception of Ethiopia and some southern African countries, ox plows were first introduced into tropical Africa around 1910, and Teso District in Uganda was one of the first locations where farmers adopted them. Animal traction also spread in Senegal, and in limited areas in a number of other countries, such as Botswana, Burkina Faso, Gambia, Kenya, Lesotho, Malawi, Mali, Nigeria, Tanzania, Zambia, and Zimbabwe.

In most of these countries, however, the spread of animal traction seemed to be linked to the introduction of a new cash crop, usually cotton or groundnuts, or maize in southern Africa. Elsewhere, farmers often seemed to be slow to adopt it. There is evidence from the Mali project, from Norman et al. (1981), and from Zimbabwe that the larger, wealthier families that own more cattle are more likely to be able to afford animal traction, which contributes considerably to their wealth, than smaller poorer families, who often have a tremendous struggle to obtain a plow and oxen. In Zimbabwe, some farmers who could not afford to keep both cows and oxen resorted to using the cows for plowing. Starkey (1986) suggested that some Senegalese and Gambian farmers used donkeys and light cultivators for the same reason.

However, there were indications from the Mali farming systems project that farmers who were unable to achieve food self-sufficiency because of low crop yields on overcropped infertile soils did not consider it worthwhile to use animal traction until a new package of maize, manure, and fertilizer was introduced, even though they already owned cattle and a few plows.

I think this supports the principle that mechanization is only valued by farmers in so far as they perceive that it reduces their constraints, including drudgery, and increases their land or labour productivity, or both, and profit margins. Wanders (1994, p. 242) has also stressed the importance of the development of a local infrastructure to support animal traction. For example, in southern Mali, there are no fewer than 2500 rural blacksmiths who can keep animal traction equipment in repair and even make equipment.

If the weeding bottleneck mentioned above is a serious constraint, it is interesting to speculate why farmers in East Africa seem to have been slow to adopt ox-weeders, even when incentives in the form of loans and subsidies were offered to them. In other parts of Africa, farmers often use plows or ridgers or weeders for weeding, and in Senegal they use the *sine houe* toolbar.

Part of the reason may have been the lack of a satisfactory seeder for row planting, but even where crops were accurately planted in rows, little interrow weeding with oxen was done. Possibly farmers found too many difficulties in training their oxen properly or considered that possible damage to their crops outweighed any reduction in the weeding bottleneck. Farmers' reluctance to adopt wheeled tool-carriers, even when they were heavily subsidized (well documented by Starkey 1988), is also of considerable interest.

Tractors and Other Mechanization

On the other hand, there are many examples of farmers' enthusiasm for tractor plowing, and their willingness to pay quite large sums of money for this operation. Where the tractors were owned and operated by the larger-scale farmers, as in the central rainlands of the Sudan or in parts of Kenya and Zambia, they seem to have been incorporated into the farming systems, although the total number of farmers involved is very small, but tractor owners or contractors would sometimes hire them out to other farmers to the profit of both. However, the evidence appears to indicate that, in general, government-organized tractor-hire schemes or group farms have not been able to operate economically without heavy subsidies (see, for example, de Wilde 1967; Carr 1982; Pingali et al. 1987).

In most countries, the first parts of the agricultural production system that are successfully mechanized are usually various aspects of crop processing, particularly grain milling. The spread of small village grain mills, mainly hammer-mills powered by small gasoline or diesel engines or, if electricity is available, by electric motors, throughout Africa is impressive. This new technology seems to have spread with little government or external support.

There appears to be increasing interest in the small-scale mechanization of other aspects of crop processing, particularly threshing and dehulling (Bassey and Schmidt 1989). Pumps for small-scale irrigation also appear to be becoming popular in some areas such as northern Nigeria, where crop prices can justify their capital and running costs.

Social Aspects

Modernization

The process of opening up what were relatively closed traditional societies has been going on for many years at varying rates in different parts of Africa. This complicated process, assisted by many factors, of which communications, education, urbanization, and external trade are but a few, has often been disruptive in its effects on fragile traditional societies. Although modernization has brought increased material benefits to some, many are still caught in the vicious cycle of poverty, malnutrition, and sickness, with less support than before from the extended family and the community. Some of the worst-off may be the landless and unemployed city slum-dwellers, as the possession of a piece of land usually provides some insurance against starvation for rural people, however poor.

Motivation

What causes farmers to change their systems? Obviously economic pressures in various forms play a large part. As outlined above, land pressure may be one of the most important but seasonal labour shortages and grinding poverty also affect decisions. Many social pressures also affect farmers' actions, as most people are reluctant to stand out against the general will and ethos of the community, particularly in strongly traditional societies. Norman et al. (1981, p. 19) have summarized some of these community norms, structures, and beliefs.

Risk Aversion

Although risk aversion can be expected to be important to people living near the margin of survival, and it is undoubtedly true that savanna farmers are generally reluctant to take undue risks, little research appears to have been done on this important topic. The priority that farmers normally place on safeguarding their food supplies is a response to risk, as is their cautious approach to new, often unproven, technology. The purchase of livestock as a "bank on the hoof" may be another response. However, there is a large body of evidence that savanna farmers will make rapid and substantial changes in their systems where the incentives outweigh the risks in their perception (see, for example, de Wilde 1967; Anthony et al. 1979).

Incentives

Like people anywhere, farmers respond to incentives and, in general, the magnitude of the response depends on the size of the incentive — Eicher and Baker (1982) have reviewed this topic exhaustively. Many of the frustrations of research and extension workers from colonial times on, caused by farmers who did not accept apparently improved technologies, were a result of two reasons. First, many of the technologies did not fit the farmers' needs and, second, the improvements did not provide sufficient incentives to farmers to change (see, for example, Anthony et al. 1979).

Analyzing experience in northeast Uganda in terms of its implications for future development, both in Uganda and elsewhere in Africa, Carr (1982, p. 72) points out that

There are two striking facts which come out of a study of the experience of the annual cropping zone of Uganda for the period that has been reviewed. The first is the rapid positive impact on the productivity of small farmers of a stable political situation combined with good infrastructure which encouraged efficient marketing and competitive pricing. The second is the underestimation by government over many years of the farmers' sensitivity of response to real price incentives. As a result of its apparent lack of understanding of the underlying forces which motivate farmers, successive governments took initiatives which reduced both the quality of marketing and the level of economic incentives to farmers. This was basically a result of the government's dichotomy of policy in which claims were made that it was concerned to encourage and protect farmers, whilst in fact its main objective was to protect other interests, increase its own revenue

and engender foreign exchange earnings which were largely used by the non-peasant farming sector of the community.
Because of this basic dichotomy, government for many years attempted to replace price and market incentives by increased agricultural services as a means of stimulating production. This often had the effect of presenting farmers with two conflicting signals. On the one hand the extension staff were pressing farmers to increase their labour input into the cotton crop through earlier planting (involving increased weeding) and higher plant populations, whilst the pricing policy was decreasing real returns per labour unit for cotton production. This remains a common feature of governments in Sub-Saharan Africa today [1982]. Political exhortation or extension pressure is applied to farmers to produce one crop whilst pricing signals encourage them to produce another. Alternatively campaigns are mounted to encourage the use of purchased inputs whilst pricing policies are reducing the benefit to cost ratio of the proposed innovation.
Whilst the experience in north and east Uganda in the middle years of this century makes it quite clear that agricultural services are not an alternative to price incentives and cannot function effectively in the face of contradictory economic signals, this does not mean that there is no potential role for such services ....
This may be the most critical issue for the improvement of African farming systems, and yet it seems to receive remarkably little attention from policymakers and others. In particular, almost no research results have been found that indicate the minimum levels of the incentives that are required to induce farmers to accept various innovations. It appears that this could be a research topic that should receive increased attention. This work could perhaps be best carried out as part of the FSR programs that are discussed in the next chapter. Care would be needed in conducting the research, particularly where crop price levels are varied to determine farmers' responses.

Food Security

African farming systems have usually provided the minimum level of subsistence food production needed for survival in most years. Until comparatively recently, in those areas where communication and transport facilities were virtually nonexistent, there was little advantage in producing a surplus for sale or exchange outside the community, because there were so many difficulties in transporting and marketing it; thus communities lived at a subsistence level. Some insurance against the risk of crop failure was provided by storing grain for a few years or by planting more cassava than was needed immediately. Surplus grain could also be exchanged for livestock in good years, and the livestock could again be exchanged for grain if times became hard.

Security within the community was built up by small reciprocal gifts of food and by fulfilling other traditional obligations. Where pressure on the land was low, these measures appear to have been sufficient to allow survival, although competition between tribes for resources, particularly land, appears to have caused conflict from early times, as it has elsewhere in the world. Also, in the drier areas, runs of unusually dry years are remembered in most communities as having caused famine. The response often seems to have been for the whole community to move to another location where food was thought to be more readily available. Famine was also sometimes caused by the depredations of locusts, rodents, and other plant or animal pests and diseases.

FAO estimated that, in 1985, there were 100 million people (about one-quarter of the population) not receiving a calory-adequate diet in sub-Saharan Africa. Although the accuracy of this figure is not known, the exploding population and the low rates of increase in food production mean that the dangers of food insecurity are constantly increasing.

Rukuni and Eicher (1987) reviewed the food-security situation in southern Africa. They recommended that the Southern African Development Coordination Committee (SADCC) and the southern African countries should adopt the World Bank definition of food security as "Access by all people at all times to enough food for an active and healthy life." The two essential elements in this definition are, first, the availability of food and, second, the ability to acquire it (World Bank 1986, p. 1).

Food security was not to be defined as being the same as *food self-sufficiency* or agricultural development, because these were narrower concepts than food security. Although food self-sufficiency might be a valid policy objective in some situations, the challenge to food-security researchers was to measure the real costs and reduction of risks associated with increasing the self-sufficiency index of a particular crop in a particular country. Similarly, agricultural development, if successful, could make a contribution to food supplies, and was essential for raising the average standard of living in the region, but should not be confused with food security.

Rukuni and Eicher (1987, p. 19) make the important point that even if a country is self-sufficient in food, this does not imply that all (or even a large proportion) of its people may have access to sufficient food at all times. Urban or landless people may not have sufficient money to buy food, and the rural poor who have land may suffer from lack of food during times of drought or during the "hungry gap" before the harvest. Therefore, access to food is as important as food availability, and research and policy action should be directed to both these aspects. They suggest six challenges for food-security researchers in the region:

- Food and agricultural production;
- Marketing, rural infrastructure, and storage;
- Raising rural per-capita incomes and generating employment in rural areas;
- Food access and nutrition;
- National food-security policy analysis; and
- Regional food-security policy analysis.

These challenges could also apply to food-security research throughout Africa: Rukuni and Eicher's provocative and well-written paper has much to say to researchers and policymakers throughout the continent.

Land Tenure

Traditionally, when population pressure over much of Africa was comparatively low, most African societies practiced various types of communal land tenure, where the family head had the rights of use of a particular area of land for as long as he needed it. Legal ownership of the land was usually held by governments, but allocation of the use of land at the local level was done by chiefs or other traditional land authorities. This right of use would normally be passed from fathers to sons — sometimes to the eldest son, but often the land was divided among the sons. This traditional system remains the basis for land tenure in most savanna countries, and Norman et al. (1981, p. 37) have suggested that it is the main reason for the relatively equitable distribution of land in most parts of Africa. Land has a deep religious and mystic significance in most African societies, in addition to being the main source of security.

As pressure on the land and "modernization" increase, and land becomes a scarce resource, land-use tends to become more individualistic, and borrowing or renting the use of land become widespread. Eventually, land is bought or sold like any other commodity, and many governments have started granting legal land titles to the owners. In parts of Uganda, particularly Buganda, land titles were granted to certain chiefs by the colonial government in the early years of the 19th century, on the basis of multiples of square miles (1 mile^2 = 2.59 km^2). Fortunately, the traditional tenure systems continued as far as the tenants occupying these *mailo* lands were concerned, and rents were held at a low level, so that there was not too much disruption of the traditional society (Richards et al. 1973). In those countries where large areas of land were alienated to foreigners, considerable hardship and friction were caused as pressure on the land increased.

In some societies with heavy population pressure, fragmentation became widespread and severe — fragmentation is the term used to describe farms that consist of several small, widely separated pieces of land. For example, fragmentation was a serious problem in parts of the Kenyan highlands, in south-west Uganda, and in the Sine–Saloum area of Senegal. Although it may be argued that some farmers could gain certain advantages from a degree of fragmentation if it enabled them to have the use of a variety of different land types suitable for various crops, in general, farming efficiency seems to decline on severely fragmented farms. The willingness of farmers in parts of Kenya to consolidate and replan their holdings appears to support this view. In particular, fencing for small-scale dairying would probably be uneconomic on severely fragmented farms. Also consolidated farms should be easier to work (see, for example, de Wilde 1967; Faye and Niang 1977).

Labour

Several economists, for example, Mellor (1984), have pointed out that smallholder labour productivity in Africa appears to be considerably lower than in Asia. A major problem in the African savanna, as elsewhere, is the marked seasonality of farm work. In their detailed discussion of labour issues, Norman et al. (1981) have emphasized the weeding bottleneck as a particularly severe one in many farming systems. In the drier areas, the critical timing of land preparation and planting may cause problems, but with modern technology and increased yields harvesting of certain crops may become a bottleneck

(Delgado 1978). Norman et al. (1981, p. 34) pointed out that farmers attempt to reduce this labour bottleneck in several ways, which include

- Working longer hours during the busy season;
- Expecting children to help with certain types of farm work;
- Hiring or otherwise obtaining extra labour — although this is often difficult because of cash shortages at bottleneck periods, and because labour may be in short supply when people are busy on their own farms;
- Growing crops in mixtures, which can help to smother weeds, and planting cash crops after food crops are well established;
- Using mechanization — in Nigeria, mechanization mainly consisted of the introduction of ox-plows or ridgers that allowed larger areas of land to be cultivated, but were not used for weeding, so they may have actually increased the weeding bottleneck; in the francophone countries, however, the rapid spread of light multiculture weeders appears to be a response to this constraint; and
- Using herbicides — in general, herbicides appear to have made rather slow progress in the region, probably mainly because the economic incentive for their use often seems doubtful, but also because they can be difficult to use in mixed crops. They may also tend to reduce soil OM. In recent years, use of herbicides has become more widespread on certain crops in some francophone countries, such as on cotton and maize in southern Mali and on rice in the Côte d'Ivoire.

Definitions of what is "man's work" and what is "woman's work" can sometimes cause bottlenecks, particularly because women are usually heavily involved in many household tasks such as fetching water and firewood, pounding of grains, cooking, and caring for children. However, when cash crops and changes in the farming systems are introduced, traditional definitions of man's and woman's work do seem to change over time. Farmers would be expected to seek new technologies that would reduce their own production constraints, and this does seem to happen slowly.

Capital

Shortage of capital is a widespread constraint in savanna farming systems. Traditional subsistence cultivators invest little capital in their farms. Their possessions include a few hand tools, home-made houses and granaries, and some livestock. Even the acquisition of a plow and a pair of oxen is a major item of capital expenditure, which appears to be beyond the reach of many of the poorer farmers. Wealthier farmers, on the other hand, who possess several head of cattle and other stock, have a considerable amount of capital tied up in livestock. There appears to be an increasing trend to purchase livestock with any profits from crop sales (Haswell 1975; Norman et al. 1981). The livestock serve as a "bank on the hoof," and an insurance policy to be cashed in if there is a need to purchase food, or fulfil social obligations, as well as a source of milk, meat, hides, skins, power for animal traction, and manure for the land (see, for example, Delgado 1978). However, if herdsmen from another tribe such as the Fulani are employed to herd the cattle, the milk may go to the herdsmen and the manure may not be used.

With increasing modernization and production for the market, gradually more inputs such as fertilizers, crop-protection chemicals, and machinery may be purchased, but capital investments in the form of fencing, water supplies, and so forth tend to remain minimal for all but the wealthiest farmers. In many areas, the poorer farmers may be so short of money that they are forced to sell a substantial proportion of crops such as groundnuts soon after harvest, when prices are often low, to obtain cash, and then to buy food or seed when they become short later in the season at much higher prices. In general, it appears that farmers are more willing to apply inputs such as fertilizers or insecticides if they are provided on credit, the cost being deducted when the crop is sold, but Eicher and Baker (1982) have questioned the real need for credit in many situations.

In recent years, the International Agricultural Research Centers (IARCs), donors, and others appear to have become more conscious of the extreme poverty of many small farmers, so that the "low-input strategy" has been widely promoted. Although this strategy may be appropriate for subsistence production, it may be counterproductive where profitable marketing opportunities exist. For example, if a high-value crop is introduced that has an assured market and that will give a high gross margin with few risks if substantial purchased inputs are provided, usually even the poorest farmers will wish to maximize their profit by applying the optimum inputs, usually with credit. In such cases, it makes no sense to try to implement a low-input strategy across the board.

On the other hand, any workable credit policy clearly requires that applicants be carefully assessed to determine whether the credit will really help increase their production and income by more than the amount loaned plus interest, and whether they are likely to be able and willing to repay the credit.

Management Levels

Although surprisingly little factual data seems to be available, it is clear that there are wide variations in levels of management between individual farmers, as is to be expected (see, for example, Haswell 1975; Matlon 1977). Although the decision-making process in extended families is complicated and often difficult for outsiders to understand, there is an increasing tendency for the traditional large families to break up and separate into nuclear families. Although these smaller families may have greater freedom to innovate, they are often limited by resource constraints. Management levels often seem to depend heavily on the past experience of the farmers. Farmers who have worked on modern commercial farms often seem to have learned many management skills (see, for example, de Wilde 1967; Anthony et al. 1979).

However, although most smallholders probably try to optimize their use of the limited resources available to them, within the limitations of their environment and background, poverty, risk, and other severe constraints do appear to slow down smallholders' adoption of some new technologies. For example, simple soil- and water-conservation practices would provide long-term benefits in farm productivity, but because the short-term costs may appear to outweigh the short-term returns, their adoption rate is often very slow. Similarly, the control of livestock numbers and the management of grazing in communal grazing areas could be expected to give substantial long-term returns to the livestock-owning community, but because the short-term gain to the individual may be reduced such control is seldom practiced.

Markets, Prices, and Inputs

Although many smallholders still seem to maintain food self-sufficiency as their first priority, nearly all of them are involved in some way in the market economy. This may consist mainly of selling a cash crop to a local marketing agency, or of buying or selling food crops in a local market. Many governments set prices to farmers for cash crops, and they may also set fixed or minimum prices for certain food crops. Prices for cash crops are often set below realistic market levels, or taxes may be deducted from them to assist in government revenue collection. These reductions can have serious effects in reducing farmers' incentives to produce (see, for example, Carr 1982).

In the case of surplus food crops, governments have often been unsuccessful in administering fixed or minimum prices. Difficulties sometimes appear to be caused by attempting to fix prices at unrealistic levels. Also, in a mainly subsistence economy, where only a small proportion of total production comes onto the market, small changes in production can lead to large changes in quantities coming onto the market.

For example, in Mali, there were deficiencies in food grains up to 1984, so the government set the minimum grain price at a fairly high level to stimulate production. The good rains in 1985, together with food aid, made up the deficit and the government's marketing agency quickly filled the available storage space. A second good season in 1986 together with a continued high price led to a substantial production surplus. Private traders lowered their prices to about half the government's price, but the government's storage space was soon filled, and the governmental agency was unable to continue buying, so that the price dropped to the market rate. Farmers who had invested in fertilizers and other inputs in the expectation of receiving the government's minimum price experienced considerable difficulties in repaying their loans. At the same time, food aid was still coming into the country, and this contributed to the fall in market prices. It seems likely that the farmers reduced their production the following season.

This problem of surpluses seems one of the most difficult to handle, particularly for land-locked countries such as Mali. It appears that the development of efficient, low-cost transport facilities should assist in the disposal of surpluses either within the region or possibly on the world market. At the same time, improved transport would allow inputs to enter at competitive prices. On the other hand, dumping of surplus production from rich countries at low prices can be disastrous. Jones (1992, p. 3) has commented on the effects of the disposal of surplus wheat stocks by the European Community at heavily subsidized prices under their Common Agricultural Policy.

In Burkina Faso in West Africa, for example, wheat was being sold in 1988 for the equivalent of [US] $60 a ton. Nobody on earth can grow wheat for as little as $60 a ton. Locally produced grains — sorghum and millet — were normally sold for around $100.

In situations like this, the urban populations develop dependence on a crop that cannot be grown at the price it is selling for, and which cannot be grown at all in that locality. Then the rural population cease to produce more than they will eat, and find themselves without money for school fees, health or anything else. The workless rural young become semi-employed or unemployed urban young.

Chapter 11: Agricultural research

Research Needs

In the past, agricultural research in the African savanna was heavily weighted on the side of cash-crop research based on research stations. There were reasons for this. When populations were still fairly small, and population pressure on the land was low in most areas, overall food-production problems were not particularly severe. The widespread fallow-farming systems, mainly based on shifting cultivation, were reasonably stable. Local food shortages as a result of the failure of the rains or of pest or disease outbreaks, did occur from time to time, but food deficits could be corrected by transport of surpluses from other more-productive areas. This was sometimes done by commercial traders but governments would act to supplement their activities when necessary (see, for example, Allan 1965).

Therefore, because food production was not generally perceived as a problem, it often did not receive priority research attention. Instead the new cash crops, especially cotton and groundnuts, which had a number of production problems, particularly those resulting from pests and diseases, received most of the research attention. For example, Wrigley (1959) has documented the vital role that cotton production by smallholders played in the early years of the 20th century in Uganda, both in providing a cash income for farmers and in building the whole economy of the country.

There were, however, exceptions. Maize and cassava breeding received considerable attention in East Africa from the 1930s onward, and maize research was also pursued in southern Africa with good results. A large increase in research budgets and staffs took place in many countries in the 1950s and 1960s, and many food crops received some research attention. Carr (1982, p. 73) has questioned whether some of these programs were as effective as they should have been and makes the following comment.

An unfortunate result of the lack of impact of research programmes in a number of countries has been a decline of interest, support and attention for their work on the part of government. Low priority is given to the financial needs of the programme, there is little overall control over strategy, and research workers often find that the only path to promotion is to leave research altogether. This is unfortunate as the continent faces increasing pressures of various kinds which make the need for technically, managerially and economically viable innovations more urgent than they have been in the past. This requires both fundamental research and a greatly increased level of field experiments if the problems of increasing production, particularly in the drier areas, are to be solved. The difference between what is required and much of the work of the past depends upon the level of understanding of the real problems of the small farmer and the appropriateness of what is offered to his actual circumstances.

Research Planning

In view of the urgent nature of the agricultural problems that are accumulating throughout the savanna, and the limited resources, including trained staff, available for research, it appears essential to ensure that none of these resources are wasted. This requires a rigorous determination of priorities and operational procedures. Although the problems of savanna agriculture are many and varied, if it is accepted that the overriding problem is one of deterioration in land-use practices, and the breakdown of smallholder farming systems throughout the savanna, this has certain implications for research.

Farming Systems Research

One way of looking at research needs as they affect the farmer is to consider them in the context of FSR. This concept has been fully described by others, such as Norman et al. (1981), Zandstra et al. (1981), and Collinson (1982). It is defined here as including both on-farm research and on-station back-up component research.

On-Farm Research

Many lessons can be learned from on-farm research, among which are the following.

- The initial research at Sakoro in Mali took about 3 years to test a wide range of possible technologies and to screen out those that could reduce the limiting constraints and were acceptable to the farmers. An additional 2 years were needed to check the results. Although this long initial period was partly due to the inexperience of the FSR team, it was essential to take sufficient time to establish a good working relationship with the villagers, and to understand their problems, constraints, and perceptions, if success were to be attained.
- The FSR team leader can be an agronomist or an agricultural economist, but must have some working knowledge of the other discipline, ability to lead a multidisciplinary team, and an insight into the constraints and potentials of smallholder farming.
- Despite the best efforts of an experienced team, it may be difficult to identify improved technologies that are sufficiently profitable to be acceptable to farmers in some villages, for reasons that are often difficult to determine. Monzondougou was an example of one of these villages. Although it may be interesting to continue working in this village in the hope of finding acceptable technologies in future, it may be more cost-effective to seek more responsive villages.
- Although FSR can be an expensive exercise, particularly when supported by donor agencies, if it is to be made a part of a resource-poor country's indigenous research program, it obviously must be conducted at a low cost. This appears to

be possible provided that researchers with an adequate level of training and motivation are available and willing to work in a group of villages, with perhaps a bicycle or low-cost motorcycle for transport, and that assistants can be recruited from the villages at local wage rates. These teams, consisting at least of an agronomist and agricultural economist, need back-up from animal, soil, and crop-protection scientists, or others as appropriate, as well as administrative support. Rapid rural appraisal or similar methods may often be appropriate as a preliminary step.

- The farmers themselves should be involved at all stages in planning and carrying out the research. Participatory research of this type can save time and money (Chambers et al. 1989).
- An all-important aspect of FSR is the link with extension. It seems doubtful if FSR should be undertaken unless an effective extension service is willing to be fully involved right from the beginning — in selecting areas for research, carrying out diagnostic surveys, identifying villages and farmers for detailed work, cooperating in on-farm trials, and eventually testing promising results by preextension trials in additional villages.
- Linkages also need to be firmly established with researchers working on research stations, who may conduct part of their own research in FSR villages. Their research programs should also be modified according to the results and needs of FSR.
- Although due caution is required in making the results of FSR known to policymakers, once proven research results become available, linkages with policymakers should be developed. A tactful way of doing this could be by holding a workshop for policymakers at which a number of fully documented options are presented.

On-farm research can be criticized as being too location-specific and therefore expensive for widespread application. Although it is true that no two farms are the same, and therefore logically on-farm research would need to be done on every farm, in practice, as in every other type of research, priorities have to be established and choices made. When the planning process indicates that on-farm research can make a useful contribution and is a wise use of resources, it needs to be properly planned with full involvement of the farmers, as an integral part of the whole research and extension program. Experience in many countries indicates that if this is done, and the research is carefully and thoroughly carried out, it can often make considerable contributions in four areas:

- Designing and testing improved technologies and systems that are profitable and acceptable to farmers;
- Reflecting back farmers' real problems and constraints to on-station research workers, and encouraging them to become involved with farmers with the aim of alleviating their problems;
- Strengthening linkages between farmers, researchers, and extension workers, providing proven technologies for extension workers to test with wider groups of farmers and, if successful, extending into larger recommendation domains; and

- Strengthening linkages between policymakers, farmers, and research and extension workers, so that feasible choices for improved agricultural-policy options are presented to governments and others.

On-Station Research

The term "on-station backup component research" is used here to include all types of research, sources of knowledge, and improved technology off-farm, which can be expected to contribute to farming systems. It is suggested that these types of research should be mainly identified and tested through the on-farm research programs, and recommended technologies should be subjected to regular rigorous analysis of their cost-effectiveness by FSR researchers. This procedure may help to avoid the risk of research being designed more and more according to the interests of the researchers, and becoming further and further removed from the needs of the farmers. In recent years in many African countries, governments have chosen to separate agricultural research from ministries of agriculture and extension services in various types of parastatal organizations. Although this may have some advantages in improving researchers' terms of service and in other ways, it can cause a further widening of the gap from the farmers' needs.

In his study of agricultural development in northern and eastern Uganda, Carr (1982, p. 74) commented on these trends.

A ... factor which has militated against the production of research results leading to viable technical packages for rain-fed farming in the savanna belt in particular, has been the pressure on research workers to embark on lines of study which will result in the publication of papers of sufficient scientific merit to further their professional careers. The field level adaptive trials and the work on simple innovations to relieve labour bottlenecks, which are a necessary part of an effective programme to produce viable recommendations for small farmers on many areas, carry less academic prestige and in consequence are unattractive to people concerned with their professional advancement and reputation in the scientific world. Without a change of emphasis which gives acclaim to work on the basis of its utility rather than solely on the level of its complexity, it will be difficult to obtain the services of the best workers to deal with many of the actual problems faced by small farmers.

Chapter 12: Future prospects

In general, the overall potential prospects for agriculture in the savanna can be promising. Much of the area enjoys an excellent climate for crop and animal production, and even the drier parts have a potential for carefully designed and executed farming or ranching systems and for irrigation where water is available. Although many of the soils are relatively fragile, most of them can be made to produce abundantly over an indefinite period with ordinary good farming practices.

The FAO Agro-Ecological Zones Project (FAO 1978) has estimated that for the whole of sub-Saharan Africa, only about one-sixth of the potential rainfed land is in use at present.

Also, the potential irrigable land is estimated at six to eight times the present irrigated area. Even at a modest intermediate level of inputs, involving improved varieties, simple crop- and animal-protection measures, some use of fertilizers, simple field tools, some soil-conservation measures, and some supplementary power, Africa as a whole should have no problems in feeding itself, and even exporting a considerable surplus. Some countries, however, particularly in the arid and subarid zones, may have difficulties in feeding themselves, and these countries will probably need to import food from neighbouring countries (Bunting 1987).

At high input levels, it is thought that Africa could feed the population of the whole world, if necessary. The potential is enormous, but the present production falls far short of the potential, and appears to be declining in many areas. It is my thesis that, in the savanna, this decline is a result of the failure of most farming systems to change and adapt sufficiently rapidly to changing conditions, particularly increasing population pressure. This failure has led to a particularly serious decline in soil productivity.

Therefore, nothing is inevitable about the overall decline in savanna farming systems, but without urgent, intelligent, and sustained action by all concerned, this decline can be expected to continue, and then the outlook becomes very gloomy. Africa is littered with poorly planned and executed agricultural projects that achieve little and often eventually fail completely. Instead of publishing the results and trying to learn from these failures, they are often conveniently forgotten so that the same mistakes may be made in the same area by a similar project within 5–10 years.

Therefore, I propose that the following urgent action needs to be taken by governments and international agencies working together, even though it is fully realized how severe are the constraints and pressures under which governments are working. Also some governments are exceptions and already have excellent programs operating.

Land-Use Management and Conservation

The extent of the problem and the most urgent areas needing attention must be defined. This could be done by setting up a national agency for land-use management and conservation, if this does not already exist. This agency could collaborate with the FAO Agro-Ecological Zones Project to extend and test the results of that project within each country, particularly to define critically at-risk areas. The agency should also have the capability to conduct detailed studies to design improved land-management systems for specific areas such as watersheds with special problems, resettlement areas, irrigation schemes, and so on.

Farming Systems Research

A strong FSR capability must be established, if it does not already exist, to work with farmers, extension workers, and others in the areas identified as needing urgent attention. Strong on-station backup component research is also needed. Results of all research and development projects, whether they succeed or fail, should be published and made widely available so that others can learn from the successes and failures.

Communications and Markets

All possible action must be taken to improve roads and other communication channels between the affected areas and national, regional, and international markets, and to encourage traders and other agencies to provide efficient markets and input supplies.

Incentives

While encouraging commercial trading activities, ways must also be sought to establish adequate incentives for farmers. These incentives should correspond to those identified by the FSR teams as most likely to correspond with farmers' needs and assist them in transforming their farming systems into productive, sustainable forms. An important part of this would have to be plans for the storage (preferably on-farm), transport, and marketing of possible surplus production. As the recently concluded (1995) General Agreement on Tariffs and Trade (GATT) talks have clearly shown, the question of incentives for farmers is an extremely difficult problem, which perhaps no country has solved to the satisfaction of all concerned. Yet its great importance indicates that it must receive priority attention from governments, but without establishing unsustainable price or other reward levels for farmers.

Training

Excellent training facilities must be established or strengthened, preferably at the national level, but failing this at the regional or international level, to train land-use, FSR, extension, and other staff to carry out these programs.

Appendix A: Populations and GNP for sub-Saharan Africa

Country	Area ('000 km^2)	Population (millions)		GNP per capita (US$)	
		1987	1993	1987	1993
Mozambique	802	14.6	15.1	170	90
Tanzania	945	23.9	28.0	180	90
Ethiopia	1097	44.8	51.9	130	100
Zaire	2345	32.6	NA	150	NA
Sierra Leone	72	3.8	4.5	300	150
Burundi	28	5.0	6.0	250	180
Uganda	236	15.7	18.0	260	180
Malawi	118	7.9	10.5	160	200
Chad	1284	5.3	6.0	150	210
Rwanda	26	6.4	7.6	300	210
Madagascar	587	10.9	13.9	210	220

Guinea-Bissau	36	0.9	1.0	160	240
Kenya	583	22.1	25.3	330	270
Mali	1240	7.8	10.1	210	270
Niger	1267	6.8	8.6	260	270
Sao Tome and	1	0.1	NA	280	NA
Principe	638	5.7	NA	290	NA
Somalia	274	8.3	9.8	190	300
Burkina Faso	924	106.6	105.3	370	300
Nigeria	2506	23.1	NA	330	NA
Sudan	57	3.2	3.9	290	340
Togo	11	0.8	1.0	220	350
Gambia	2	0.4	NA	370	NA
Comoros	753	7.2	8.9	250	380
Zambia	623	2.7	3.2	330	400
Central African	113	4.3	5.1	310	430
Republic	239	13.6	16.4	390	430
Benin	111	2.3	NA	450	NA
Ghana	4	0.3	NA	500	NA
Liberia	246	6.5	6.3	NA	500
Cape Verde	1026	1.9	2.2	440	500
Guinea	391	9.0	10.7	580	520
Mauritania	322	11.1	13.3	740	630
Zimbabwe	30	1.6	1.9	370	650
Côte d'Ivoire	17	0.7	NA	700	NA
Lesotho	197	7.0	7.9	520	750
Swaziland	475	10.9	12.5	970	820
Senegal	342	2.0	2.4	870	950
Cameroon	824	NA	1.5	NA	1820
Congo	582	1.1	1.4	1050	2790
Namibia	1221	NA	39.7	NA	2980
Botswana	2	1.0	1.1	1490	3030
South Africa	NA	0.1	NA	3120	NA
Mauritius	268	1.1	1.0	2700	4960
Seychelles	1247	9.2	NA	NA	NA
Gabon	22	0.4	NA	NA	NA
Angola	28	0.4	NA	NA	NA
Djibouti					
Equatorial					
Guinea					

Source: World Bank 1989 and 1995, table 1.
Note: NA = not available.

Appendix B: Abbreviations

IER	Institut d'économie rurale, Mali
BNF	biological nitrogen fixation
CEC	cation exchange capacity
CFAR	Centres de formation d'animateurs ruraux
CFDT	Compagnie française pour le développement des fibres textiles (now CMDT)
CIDR	Compagnie internationale de développement rurale
CIRAD	Centre de coopération internationale en recherche agronomique pour le développement
CMDT	Compagnie malienne pour le développement des fibres textiles
EAAFRO	East African Agricultural and Forestry Research Organisation
FAO	Food and Agriculture Organization of the United Nations
FSR	farming systems research
GATT	General Agreement on Tariffs and Trade
GDP	gross domestic product
GNP	gross national product
IARCs	International Agricultural Research Centres
ICRAF	International Council for Research in Agroforestry
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IDRC	International Development Research Centre
IRHO	Institut de recherches pour les huiles et oléagineaux
ISRA	Senegalese agricultural research institute (Institut sénégalais de recherches agricoles
ITCZ	Inter-Tropical Convergence Zone
KIOF	Kenya Institute of Organic Farming
MAD	Mobilizing against Desertification
ME	man-equivalent
NGOs	nongovernmental organizations
OM	organic matter
SADCC	Southern African Development Coordination Committee
WMO	World Meteorological Organization

Appendix C: Latin names of crops

African mango	*Cordyla africana*
Avocado	*Persea gratissima*
Bambara groundnut	*Voandzeia subterranea*

Banana	*Musa* spp.
Breadfruit	*Artocarpus incisa*
Cassava	*Manihot esculenta*
Cocoa	*Theobroma cacao*
Cocoyam	*Colocasia* spp.
Coffee arabica	*Coffea arabica*
Coffee robusta	*Coffea canephora*
Cotton	*Gossypium hirsutum*
Cowpea	*Vigna unguiculata*
Groundnut	*Arachis hypogaea*
Hemp	*Hibiscus cannabinus*
Henna	*Lawsonia alba*
Jackfruit	*Artocarpus integrifolia*
Kola	*Cola acuminata*
Locust bean	*Parkia clappertoniana*
Loquat	*Photinia japonica*
Maize	*Zea mais*
Mango	*Mangifera indica*
Millet	
finger	*Eleusine coracana*
pearl	*Pennisetum typhoideum*
Oil palm	*Elaeis guineensis*
Okra	*Hibiscus sabdariffa*
Pepper	*Piper nigrum*
Pigeon pea	*Cajanus cajan*
Pineapple	*Ananas sativus*
Plantain	*Musa* spp.
Potato	
solanum	*Solanum tuberosum*
sweet	*Ipomoea batatas*
Pyrethrum	*Chrysanthemum cinerariaefolium*
Rice	*Oryza sativa*
Rubber	*Hevea brasiliensis*
Sesame	*Sesamum indicum*
Sisal	*Agave sisalana*
Sorghum	*Sorghum bicolor*
Squash	*Cucurbita* spp.

Sugarcane	*Saccharum officinarum*
Tea	*Thea sinensis*
Teff	*Eragrostis teff*
Tobacco	*Nicotiana tabacum*
Tomato	*Lycopersicon esculentum*
Watermelon	*Citrullus lanatus*
Yam	*Dioscorea* spp.

References

- Agabawi, K.A. 1970. The raingrown sorghum development, Sudan Republic. *In* Bunting, A.H., ed., Change in agriculture. Duckworth, London, UK. pp. 567–576.
- Ahn, P. 1970. West African soils. Oxford University Press, London, UK. 332 pp.
- Allan, W. 1965. The African husbandman. Oliver and Boyd, Edinburgh, UK. 503 pp.
- Anthony, K.R.M.; Johnson, B.F.; Jones, W.O.; Uchendu, V.C. 1979. Agricultural change in tropical Africa. Cornell University Press, Ithaca, NY, USA. 326 pp.
- Atteh, D. 1980. Resources and decisions: peasant farmer agricultural management and its relevance for rural development planning in Kwara State, Nigeria. University of London, UK. PhD thesis.
- Aubert, G. 1968. Classification des sols utilisée par les pedologues francais. Food and Agriculture Organization of the United Nations, Rome, Italy. World Soil Resources Report 32.
- Aubert, G.; Tavernier, A. 1972. The soils of Africa. *In* Soils of the humid tropics. National Academy of Sciences, Washington, DC, USA. pp. 17–44.
- Bassey, M.W.; Schmidt, O.G. 1989. Abrasive disc dehullers in Africa: from research to dissemination. International Development Research Centre, Ottawa, ON, Canada. IDRC-270e, 98 pp.
- Bennett, H.H. 1939. Soil conservation. McGraw-Hill, New York, NY, USA. 993 pp.
- Bilquez, A.F. 1975. Amélioration des mils au Sénégal: synthese des résultats obtenus au cours des quatre premières annees de travail at conclusions generales. Institut Sénégalais de Recherches Agricoles, Dakar, Senegal. Mimeo.
- Birch, H.F. 1958. The effect of soil drying on humus decomposition and nitrogen availability. Plant and Soil, 10, 9–31.
- Birch, H.F.; Friend, M.T. 1956. The organic matter and nitrogen status of East African soils. Journal of the Soil Science Society of America, 7, 156–167.
- Blackie, J.R.; Edwards, K.A.; Clarke, R.T. 1979. Hydrological research in East Africa. East African Agricultural and Forestry Journal, 43 (special issue), 314 pp.
- Boserup, E. 1965. The conditions of agricultural growth: the economics of agrarian change under population pressure. Allen and Unwin, London, UK.
- Brown, L.H.; Cocheme, J. 1969. A study of the agroclimatology of the highlands of eastern Africa. FAO–UNESCO–WMO Interagency project on agroclimatology, Food and Agriculture Organization, Rome, Italy. 330 pp.

- Brown, L.; Wolf, E.C. 1985. Reversing Africa's decline. Worldwatch Institute, Washington, DC, USA. Paper 65.
- Bunting, A.H. 1987. Essential economic and technological ingredients for meeting present and future food requirements in sub-Saharan Africa. Reading University, UK.
- Burnham, P. 1980. Changing agricultural and pastoral ecologies in the West African savanna region. *In* Harris, D.R., ed., Human ecology in savanna environments. Academic Press, New York, NY, USA.
- Carr, S. 1982. The impact of government intervention on smallholder development in North and East Uganda. Wye College, University of London, UK. ADU Occasional Paper 5, 88 pp.
- Chambers, R.; Pacey, A.; Thrupp, L.A., ed. 1989. Farmer first: farmer innovation and agricultural research. Intermediate Technology Publications, London, UK. 219 pp.
- Charreau, C. 1974. Soils of tropical dry and dry-wet climatic areas and their use and management: a series of lectures (spring semester). Cornell University. Ithaca, NY, USA.
- Charreau, C.; Nicou, R. 1971. L'amélioration du profil culturel dans les sols sableux et sablo-argileux de la zone tropicale seche ouest-africaine et ses incidences agronomiques (d'apres les travaux des chercheurs de l'IRAT en Afrique de l'ouest). Agronomie Tropicale (Paris) 26.
- Charreau, C.; Vidal, P. 1965. Influence de l'Acacia albida Del. sur le sol, la nutrition minéral et les rendements des mils Pennisetum au Sénégal. Agronomie Tropicale, 20(7), 600–626
- Chase, R.G.; Boudouresque, E. 1989. A study of methods for the revegetation of barren crusted Sahelian forest soils. *In* Soil, crop and water management for rainfed agriculture in the Sudano–Sahelian zone: proceedings of an international workshop, 11–16 January 1987, ICRISAT Sahelian Centre, Niamey, Niger. International Crops Research Institute for the Semi-Arid Tropics, Patancheru, AP, India. pp. 125–136.
- Cheatle, R.J.; Njoroge, S.N.J. 1993. Smallholder adoption of some land husbandry practices in Kenya. *In* Hudson, N.; Cheatle, R.J., ed., Working with farmers for better land husbandry. Intermediate Technology Publications with World Association of Soil and Water Conservation, London, UK. pp. 130–140.
- Chevalier, A. 1900. Les zones et les provinces botanique l'ADFC. Academie des Sciences, Paris, France. 130 pp.
- Cochemé, J.; Franquin, P. 1967. An agroclimatology survey of a semiarid area in Africa south of the Sahara. World Meteorological Organisation, Geneva, Switzerland. Technical Note 86, 136 pp.
- Collinson, M.P. 1982. Farming systems research in eastern Africa: the experience of CIMMYT and some national agricultural research services, 1976–81. Department of Agricultural Economics, Michigan State University, East Lancing, MI, USA. MSU International Development Paper 3.
- ______ 1989. Small farmers and technology in Eastern and Southern Africa. Journal for International Development, 1 (special issue, The Green Revolution in Africa), 66–83

- Dancette, C. 1978. Water requirements and adaptations to the rainy season of millet in Senegal. *In* Proceedings of the international workshop on the agroclimatological research needs of the semi-arid tropics. International Crops Research Institute for the Semi-Arid Tropics, Patancheru, AP, India. pp. 106–127.
- De Wilde, J.C. 1967. Experiences with agricultural development in tropical Africa — Volume 2: The case studies. Johns Hopkins Press, Baltimore, MD, USA. 466 pp.
- Delgado, C.L. 1978. Livestock versus foodgrain production in southern Upper Volta; a resource allocation analysis. Centre for Research on Economic Development, University of Michigan, Ann Arbor, MI, USA.
- D'Hoore, J.L. 1964. Soil map of Africa, scale 1 to 5 000 000 explanatory monograph. CCTA, Lagos, Nigeria.
- Eicher, C.K.; Baker, D.C. 1982. Research on agricultural development in sub-Saharan Africa: a critical survey. Department of Agricultural Economics, Michigan State University, East Lansing, MI, USA. MSU International Development Paper 1, 335 pp.
- Eriksson, J.; Gerremo, I.; Skoog, D.; Sumer-Lind, M. 1980. Soil conservation in Kenya: 1980 review. Nairobi, Kenya. 51 pp.
- FAO (Food and Agriculture Organization of the United Nations). 1978. Report on the Agro-Ecological Zones Project — Volume 1: Methodology and results for Africa. FAO, Rome Italy. World Soil Resources Project 48, 158 pp.
- FAO; Unesco (Food and Agriculture Organization of the United Nations; United Nations Educational, Scientific and Cultural Organisation). 1974. Soil map of the world: volume VI — Africa. Unesco, Paris, France.
- Faye, J.; Niang, M. 1977. An experience in agrarian restructuration and Senegalese rural space planning. African Environment, 2(4), 143–153.
- Fournier, F. 1962. Map of erosion danger in Africa south of the Sahara. Technical Centre for Agricultural and Rural Cooperation, European Economic Community, Waganingen, Netherlands.
- Fresco, L.O. 1986. Cassava in shifting cultivation: a systems approach to agricultural technology development in Africa. Royal Tropical Institute, Amsterdam, Netherlands. 240 pp.
- Gamble, D.P. 1955. Economic conditions in two Mandinka villages, Kerewan and Keneba. Colonial Office, London, UK.
- Goldsworthy, P.R.; Heathcote, R.G. 1963. Fertilizer trials with groundnuts in northern Nigeria. Empire Journal of Experimental Agriculture, 31, 351–366.
- Greenland, D.J. 1985. Nitrogen and food production in the tropics: contributions from fertilizer nitrogen and biological nitrogen fixation. *In* Kang, B.T.; van der. Heide, J., ed., Nitrogen management in farming systems in the humid and subhumid tropics. Institute of Soil Fertility and the International Institute of Tropical Agriculture, Haren, Netherlands. pp. 9–38.
- Grove, A.T. 1961. Population densities and agriculture in northern Nigeria. *In* Barber, K.M.; Prothero, R.M., ed., Essays on African population. Routledge and Kegan Paul, London, UK.
- Hardy, F. 1946. Seasonal fluctuations of soil moisture and nitrate in a humid tropical climate. Tropical Agriculture (Trinidad), 23, 40–49.

- Harris, D.R., ed. 1980. Human ecology in savanna environments. Academic Press, London, UK.
- Harrison, P. 1987. The greening of Africa. International Institute for Environment and Development — Earthscan, Paladin, London, UK. 380 pp.
- Harrison Church, R.J.; Clarke, J.I.; Clarke, P.J.H.; Henderson, H., Jr. 1965. Africa and the islands. Longmans, London, UK.
- Haswell, M.R. 1953. Economics and agriculture in a savanna village. London, UK, Colonial Research Study 8.
- ______ 1963. The changing pattern of economic activity in a Gambian village. Her Majesty's Stationary Office, London, UK. Overseas Research Publication 2.
- ______ 1975. The nature of poverty. MacMillan, London, UK.
- Higgins, G.M.; Kassam, A.H.; Naiken, L.; Fischer, G.; Shah, M.M. 1982. Potential population supporting capacities of lands in the developing world. Food and Agriculture Organization of the United Nations, Rome, Italy. Technical report of project FPA/INT/513, 139 pp.
- Hill, P. 1972. Rural Hausa: a village and a setting. Cambridge University Press. London, UK.
- Hudson, N. 1981. Soil conservation. Batsford, London, UK. 324 pp.
- Hutchinson, P. 1989. Climatic zoning for agroforestry in Somalia. *In* Meteorology and agroforestry. International Council for Research in Agroforestry, Nairobi, Kenya. pp. 201–210.
- ICRAF (International Council for Research in Agroforestry). 1989. Meteorology and agroforestry: proceedings of an international workshop on the application of meteorology to agroforestry systems planning and management, Nairobi, 9–13 February 1987. ICRAF, Nairobi, Kenya. 546 pp.
- ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1989. Soil, crop and water management systems for rainfed agriculture in the Sudano–Sahelian zone: proceedings of an international workshop, 11–16 January 1987, ICRISAT Sahelian Centre, Niamey, Niger. ICRISAT, Patancheru, AP, India. 385 pp.
- ______ 1994. ICRISAT now: sowing for the future. ICRISAT, Patancheru, AP, India. 88 pp.
- IDRC (International Development Research Centre). 1993. Farming in the city: the rise of urban agriculture. IDRC, Ottawa, ON, Canada. IDRC Reports 21 (3).
- IER (Institut d'économie rurale). 1977. Pour un programme de recherche sur les systemes de production agricole. IER, Bamako, Mali.
- ______ 1979 on (annual). Rapport annuel: Division de recherche sur les systems de production rurale. Ministère d'Agriculture, Bamako, Mali.
- ITP (Intermediate Technology Publications). 1985. Tools for agriculture; a buyer's guide to appropriate equipment. Intermediate Technology Publications, London, UK. 264 pp.
- Jones, C. 1992. A CAP on farm surpluses. Agricultural Christian Fellowship Bulletin, 1992 (Summer), 3.
- Jones, M.J. 1987. The environmental limitations of rainfed cropping. *In* Agronomic adjustment to the environment of the 400–600 mm rainfall zone of southern Africa: proceedings of a SADCC workshop held in Harare, Zimbabwe,

September 1983. Southern African Centre for Cooperation in Agricultural Research, Gaborone, Botswana. pp. 4–16

- Jones, M.J.; Wild, A. 1975. Soils of the West African savanna. Commonwealth Agricultural Bureau, Farnham Royal, UK.
- Jurion, R.; Henry, J. 1969. Can primitive farming be modernised? INEAC, Brussels, Belgium. Horticultural Series.
- Karamura, E.B. 1991. Banana/plantain production constraints as a basis for selecting research priorities. *In* Proceedings of the Regional Advisory Committee Meeting, Kampala, Uganda, 23–25 September 1991. Regional Network for Eastern Africa, International Network for the Improvement of Bananas and Plantains, Montpellier, France. pp. 21–25.
- Ker, A.D.R. 1966. Agriculture in Bukedi District, Uganda. Department of Agriculture, Entebbe, Uganda. 144 pp.
- Ker, A.D.R.; Moorse, M.W.; Watts, E.R.; Gill, B.N. 1978. Agriculture in East Africa. Edward Arnold, London, UK. 218 pp.
- Kleene, P. 1984. Experimental approaches in southern Mali. *In* Matlon, P.J.; Cantrell, R.; King, D.; Benoit-Cattin, M., ed., Coming full circle: farmers' participation in the development of technology. International Development Research Centre, Ottawa, ON, Canada. IDRC-189e, pp. 131–138.
- Kowal, J.M.; Kassam, A.H. 1978. Agricultural ecology of savanna: a study of West Africa. Clarendon Press, Oxford, UK.
- Krause, M.; Kadi, M.; Reddy, C.; Deuson, R.; Mahaman, I. 1989. Considérations économique et agro-écologique pour l'adoption des technologies nouvelles par l'exploitant. *In* Soil, crop and water management for rainfed agriculture in the Sudano–Sahelian zone: proceedings of an international workshop, 11–16 January 1987, ICRISAT Sahelian Centre, Niamey, Niger. International Crops Research Institute for the Semi-Arid Tropics, Patancheru, AP, India. pp. 353–362.
- Kydd, J. 1989. Maize research in Malawi: lessons from failure. Journal of International Development, 1 (special issue, The Green Revolution in Africa), 112–143.
- Lal, R. 1974. Soil erosion and shifting agriculture. Food and Agriculture Organization of the United Nations, Rome, Italy. Soils Bulletin, 24, 48–71.
- ______ 1983. No-till farming: soil and water conservation and management in the humid and subhumid tropics. International Institute of Tropical Agriculture, Ibadan, Nigeria. Monograph 2, 64 pp..
- Lal, R.; Sanchez, P.A.; Cummings, R.W. 1986. Land clearing and development in the tropics. A.A. Balkema, Rotterdam, Netherlands. 440 pp.
- Lang, M.G.; Cantrell, R.P. 1984. Accenting the farmer's role: Purdue Farming Systems Unit. *In* Matlon, P.J.; Cantrell, R.; King, D.; Benoit-Cattin, M., ed., Coming full circle: farmers' participation in the development of technology. International Development Research Centre, Ottawa, ON, Canada. IDRC-189e, pp. 63–70.
- Le Houerou, H.N.; Popov, G.F. 1981. An eco-climatic classification of intertropical Africa. Food and Agriculture Organization of the United Nations, Rome, Italy. Plant Production and Protection Paper 31.

- Manning, H.L. 1958. The statistical assessment of rainfall probability and its application in Uganda agriculture. Proceedings of the Royal Society (B), 144, 460–480.
- Matlon, P.J. 1977. The size distribution, structure and determinants of personal income among farmers in the north of Nigeria. Cornell University, Ithaca, NY, USA. PhD thesis.
- ______ 1984. Technology evaluation: five case studies from West Africa. *In* Matlon, P.J.; Cantrell, R.; King, D.; Benoit-Cattin, M., ed., Coming full circle: farmers' participation in the development of technology. International Development Research Centre, Ottawa, ON, Canada. IDRC-189e, pp. 95–118.
- McNamara, R.S. 1985. The challenges for sub-Saharan Africa. Sir John Crawford Memorial Lecture, [World Bank,] Washington, DC, USA. 49 pp.
- Mellor, J.W. 1984. The changing world food situation: a CGIAR perspective. Consultative Group on International Agricultural Research, Washington, DC, USA.
- Milne, G. 1935. Composite units for the mapping of complex soil associations. Transactions of 3rd International Congress of Soil Science, 1, 345–347.
- Ministry of Agriculture and Cooperatives. 1963. Report on Uganda Census of Agriculture. Government Printer, Entebbe, Uganda.
- ______ 1966. Report on Uganda Census of Agriculture: volume III. Government Printer, Entebbe, Uganda.
- Netting, R. 1968. Hill farmers of Nigeria: cultural ecology of the Kofyar of the Jos Plateau. University of Washington Press. Seattle, WA, USA.
- Norman, D.W.; Fine, J.C.; Goddard, A.D.; Pryor, D.H.; Kroeker, W.J. 1976. A socio-economic study of three villages in the Sokoto close-settled zone — Part 3: Input-output study; volume 1: text. Ahmadu Bello University, Zaria, Nigeria. Samaru Miscellaneous Paper 64.
- Norman, D.W.; Newman, M.D.; Ouedraogo, I. 1981. Farm and village production systems in the semi-arid tropics of West Africa: an interpretive review of research. International Crops Research Institute for the Semi-Arid Tropics, Patancheru, AP, India. Research Bulletin 4, volume 1, 94 pp.
- Norman, D.W.; Pryor, D.H.; Gibbs, C.J.N. 1979. Technical change and the small farmer in Hausaland, northern Nigeria. Michigan State University, East Lansing, MI, USA.
- Nyamudeza, P.; Mazhangara, E.; Busangavanye, T.; Jones, E. 1993. Farmer adoption of improved water management on vertisols in semiarid southeast Zimbabwe. *In* Hudson, N; Cheatle, R.J., ed., Working with farmers for better land husbandry. Intermediate Technology Publications and World Association of Soil and Water Conservation, London, UK. pp. 197–202.
- Nye, P.H.; Greenland, D.J. 1960. The soil under shifting cultivation. Commonwealth Bureau of Soils, Commonwealth Agricultural Bureaux, Farnham Royal, UK. Technical Communication 51, 156 pp.
- Odum, H.T. 1983. Systems ecology. Wiley, New York, NY, USA.
- Okigbo, B.N. 1984. Improved permanent production systems as an alternative to shifting intermittent cultivation. *In* Improved production systems as an alternative

to shifting cultivation. Food and Agriculture Organization of the United Nations, Rome, Italy. Soils Bulletin, 53, 1–100.

- ______ 1985. Land use and production potentials of African savanna. *In* Tothill, J.C.; Mott, J.J., ed., Ecology and management of the world's savannas. Australian Academy of Science, Canberra, Australia.
- Ouedraogo, I.; Newman, M.D.; Norman, D.W. 1982. The farmer in the semi-arid tropics of West Africa: a partially annotated bibliography. International Crops Research Institute for the Semi-Arid Tropics, Patancheru, AP, India. Research Bulletin 4, volume 2, 122 pp.
- Parsons, D.J. 1970. Agricultural systems. *In* Jameson, J.D., ed., Agriculture in Uganda. Ministry of Agriculture and Forestry, Uganda, and Oxford University Press, London, UK. pp. 127–138.
- Pelissier, R.P. 1966. Les paysans du Sénégal. Imprimerie Fabregue, Saint-Yrieix, France.
- Pereira, H.C. 1981. Land use management on tropical watersheds. *In* Lal, R.; Russell, E.W., ed., Tropical agricultural hydrology. Wiley, Chichester, Sussex, UK. pp. 3–10.
- Pereira, H.C.; McCulloch, J.S.G.; Dagg, M.; Kerfoot, O.; Hosegood, P.H.; Pratt, M.A.C. 1962. Hydrological effects of change. *In* Land use in some East African catchment areas. East Africa Agriculture and Forestry Journal, Special Issue, 27, 131 pp.
- Phillips, J. 1959. Agriculture and ecology in Africa: a study of actual and potential development south of the Sahara. Faber and Faber, London, UK. 424 pp.
- Pieri, C. 1974. L'acidification des terres de cultures exondées au Sénégal. Institut de Récherche Agronomique Tropicale, Senegal. Mimeo.
- Pingali, P.; Bigot, Y.; Binswanger, H.P. 1987. Agricultural mechanisation and the evolution of farming systems in sub-Saharan Africa. World Bank and Johns Hopkins University Press, Baltimore, MD, USA. 216 pp.
- Rauch, D. 1993. Mobilizing farmers to counter desertification in Nyanza District, Kenya. *In* Hudson, N; Cheatle, R.J., ed., Working with farmers for better land husbandry. Intermediate Technology Publications with the World Association of Soil and Water Conservation, London, UK. pp. 190–196.
- Richards, A.I., ed. 1952. Economic development and tribal change. East African Institute of Social Research and Heffer, Cambridge, UK.
- Richards, A.I.; Sturrock, F.; Fortt, J.M., ed. 1973. Subsistence to commercial farmers in present day Buganda: an economic and anthropological survey. Cambridge University Press, Cambridge, UK.
- Richards, P. 1985. Indigenous agricultural revolution. Hutchinson, London, UK, and Westview Press, Boulder, CO, USA. 192 pp.
- Rohrbach, D.D. 1987. A preliminary assessment of factors underlying the growth of communal maize production in Zimbabwe. *In* Rukuni, M.; Eicher, C.K., ed., Food security for southern Africa. UZ/MSU Food Security Project, Department of Agricultural Economics and Extension, University of Zimbabwe, Harare, Zimbabwe. pp. 145–185
- Roose, E.J. 1967. Dix années de mesure de l'erosion et du ruissellement au Sénégal. Agronomie Tropicale, 22(2), 123–152.

- ______ 1977. Applications of the universal soil loss equation of Wischmeier and Smith in West Africa. *In* Greenland, D.J.; Lal, R., ed., Soil conservation and management in the humid tropics. Wiley, Chichester, Sussex, UK.
- ______ 1989. Gestion conservatoire des eaux et de la fertilite des sols dans les paysages soudano–saheliens de l'Afrique Occidentale. *In* Soil, crop and water management for rainfed agriculture in the Sudano–Sahelian zone: proceedings of an international workshop, 11–16 January 1987, ICRISAT Sahelian Centre, Niamey, Niger. International Crops Research Institute for the Semi-Arid Tropics, Patancheru, AP, India. pp. 55–72
- Rubaihayo, P.R.; Gold, C.S. 1993. Rapid rural appraisal of highland banana production in Uganda. Infomusa, 2(1), 15–16
- Rukuni, M.; Eicher, C.K., ed. 1987. Food security for southern Africa. UZ/MSU Food Security Project, Department of Agricultural Economics and Extension, University of Zimbabwe, Harare, Zimbabwe. 406 pp
- ______ 1987. The food security equation in southern Africa. *In* Rukuni, M.; Eicher, C.K. ed., Food security for Southern Africa. UZ/MSU Food Security Project, Department of Agricultural Economics and Extension, University of Zimbabwe, Harare, Zimbabwe. pp. 3–46.
- Russell, E.W., ed. 1962. The natural resources of East Africa. East African Literature Bureau, Nairobi, Kenya. 312 pp.
- Ruthenberg, H. 1971. Farming systems in the tropics (1st ed.). Clarendon Press, Oxford, UK. 313 pp.
- ______ 1980. Farming systems in the tropics (3rd ed.). Clarendon Press, Oxford, UK. 424 pp.
- Salah el-Din el-Shazall, I. 1980. Beyond under-development: structural constraints on the development of productive forces among the Jok Gor, the Sudan. Department of Social Anthropology, University of Bergen, Norway, Occasional Paper 22. [Summarized in Food and Agriculture Organization of the United Nations (1984) Institutional aspects of shifting cultivation in Africa.]
- Sanchez, P.A. 1976. Properties and management of soils in the tropics. Wiley, New York, NY, USA. 618 pp.
- Scott, R.M. 1972. Soils. *In* Morgan, W.T.W., ed., East Africa: its people and resources. Oxford University Press, Nairobi, Kenya. pp. 95–106.
- Shaner, W.W.; Philipp, P.F.; Schmehl, W.R. 1982. Farming systems research and development: guidelines for developing countries. Westview Press, Boulder, CO, USA.
- Sokoine University. 1993. Socio-economic study of the project villages in Dodoma. Department of Agricultural Engineering and Land Use, Sokoine University of Agriculture, Morogoro, Tanzania.
-
- Starkey, P. 1986. Draught animal power in Africa: priorities for development, research and liaison. Farming Systems Support Project, University of Florida, Gainesville, FL, USA. Networking Paper 14, 40 pp.
- ______ 1988. Animal-drawn wheeled tool carriers: perfected yet rejected. Deutsches Zentrum fur Entwicklungstechnologien, Vieweg, Braunschweig, Germany.

- Stewart, J.I. 1989. Potential for response farming in sub-Saharan Africa *In* Soil, crop and water management for rainfed agriculture in the Sudano–Sahelian zone: proceedings of an international workshop, 11–16 January 1987, ICRISAT Sahelian Centre, Niamey, Niger. International Crops Research Institute for the Semi-Arid Tropics, Patancheru, AP, India. pp. 255–254
- Swynnerton, R.J.M. 1954. A plan to intensify the development of African agriculture in Kenya. Government Printer, Nairobi, Kenya.
- Sys, C.A.; Van Wambeke, R.; Frankart, P. 1961. La cartographie des sols au Congo, ses principes et ses methodes. Institut national pour l'étude agronomique du Congo, Brussels, Belgium. Series Techniques 66.
- Thomas, D.B.; Edwards, K.A.; Barber, R.G.; Hogg, I.G.G. 1981. Runoff erosion and conservation in a representative catchment in Machakos District, Kenya. *In* Lal, R.; Russell, E.W., ed., Tropical agricultural hydrology. Wiley, Chichester, Sussex, UK. pp. 395–420.
- Tothill, J.D., ed. 1948. Agriculture in the Sudan. Oxford University Press, London, UK. 974 pp.
- Toulmin, C. 1983. Herders and farmers or farmer–herders and herder–farmers? Agricultural Administration Unit, Overseas Development Institute, London, UK. Pastoral Network Paper 15d.
- Uchendu, V.C.; Anthony, K.R.M. 1975. Agricultural change in Teso District, Uganda. Nairobi, Kenya. Mimeo.
- UNICEF (United Nations Children's Fund). 1983. Annual report. UNICEF, New York, NY, USA.
- University of Wyoming. 1990. Somalia: Bay Region dryland agricultural research: final report 1983–88 (USAID Project 649-0113). University of Wyoming, Laramie, WY, USA.
- Upton, M. 1967. Agriculture in south western Nigeria. University of Reading, UK. Development Studies 3.
- USDA (United States Department of Agriculture). 1975. Soil taxonomy. US Government Printing Office, Washington, DC, USA.
- Wanders, A.A. 1994. Supply and distribution of implements for animal traction: an overview with region-specific scenarios. *In* Starkey, P.; Mwena, E.; Stares, J., ed., Improving animal traction technology: proceedings of the 1st workshop of the Animal Traction Network for Eastern and Southern Africa held 18–23 January 1992, Lusaka, Zambia. Technical Centre for Agricultural and Rural Cooperation, Wageningen, Netherlands. pp. 226–243.
- Wischmeier, W.H.; Smith, D.D. 1978. Predicting rainfall erosion losses: a guide to conservation planning. United States Department of Agriculture, Washington, DC, USA. Agricultural Handbook 537.
- World Bank. 1981. Accelerated development in sub-Saharan Africa: an agenda for action. World Bank, Washington, DC, USA. 198 pp.
- ______ 1984. Toward sustained development in sub-Saharan Africa: a joint program of action. World Bank, Washington, DC, USA. 102 pp.
- ______ 1986a. Irrigation in Africa south of the Sahara: a study with particular reference to investment for food production. World Bank, Washington, DC, USA.

- ______ 1986b. Poverty and hunger: issues and options for food security in developing countries. World Bank, Washington, DC, USA.
- ______ 1989. Sub-Saharan Africa: from crisis to sustainable growth. World Bank, Washington, DC, USA.
- ______ 1995. World development report. World Bank, Washington, DC, USA.
- Wrigley, C.C. 1959. Crops and wealth in Uganda: a short agrarian history. East African Institute of Social Research, Kampala, Uganda. 82 pp.
- Zandstra, H.G.; Price, E.C.; Litsinger, J.A.; Moris, R.A. 1981. A methodology for on-farm cropping systems research. International Rice Research Institute, Los Baños, Philippines. 147 pp.