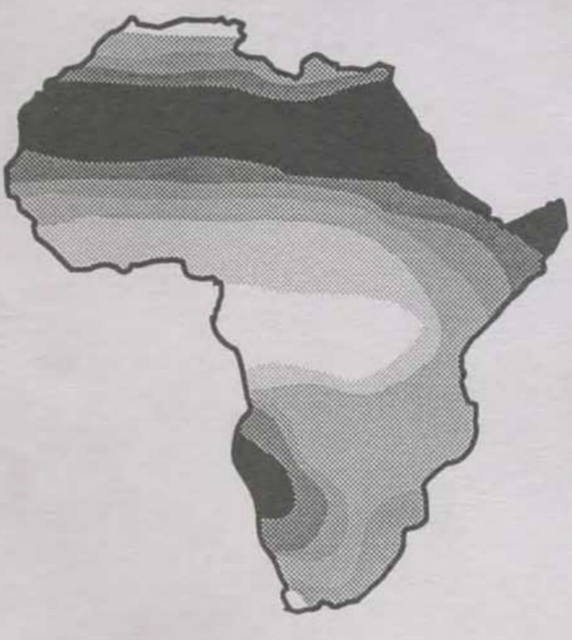
Development of Sustainable Agricultural Production Systems in Africa

Roles of International Agricultural Research Centers and National Agricultural Research Systems

by
Bede N. Okigbo



Based on the first lecture in the Distinguished African Scientist Lecture Series delivered at the International Institute of Tropical Agriculture, Ibadan, on 26 April 1989

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Bede N. Okigbo

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About the Lecture Series

The Distinguished African Scientist Lecture Series was initiated by IITA's Board of Trustees in honor of a former Deputy Director General of IITA, Dr. Bede N. Okigbo, whose knowledge of agriculture has been described as encyclopedic. Dr. Okigbo himself delivered the first lecture in the series.

Editing: D. R. Mohan Raj
Design: Jide Ojurongbe

Copies of this publication may be requested from

Publications Unit
IITA
Oyo Road, PMB 5320
Ibadan, Nigeria

Telex: 31159 or 31417 TROPIB NG

February 1991

Printed by Intec Printers Limited, Ibadan

Development of Sustainable Agricultural Production Systems in Africa: Roles of International Agricultural Research Centers and National Agricultural Research Systems[1]

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The Current Concern About Sustainability

There is widespread concern about sustainability in agricultural production and development programs. Hardly a day passes without an article, conference, seminar, radio or television program, or publication on agricultural research and development devoted to one or more aspects of sustainability in agriculture and development. This emphasis on sustainability has arisen from increasing worldwide concern about environmental degradation and various related processes, such as soil erosion and degradation, and loss in genetic diversity, which are known to have adverse effects on agricultural productivity. This increasing concern about pollution and deterioration of environmental quality has been building momentum since Silent Spring (Carson 1963), and it has given rise to environmental movements, political parties, and various organizations that are now spearheading political activism and campaigns for changes in policies, laws, technologies, and development strategies in order to safeguard man's life support system and enhance environmental quality.

This concern is pervasive in both developed and developing countries. According to Swaminathan (1988) "ecological fires are raging in most parts of the world" as a result of "deforestation, desertification, demographic pressures, soil erosion and water pollution" in the developing countries and "acid rain, atmospheric pollution, contaminated water, environmental mutagens and carcinogens and toxic waste" in the developed countries. It has been observed that while the pollution and environmental degradation caused by the assault on the environment results from poverty in the developing countries, it is the result of wealth in the developed countries (Mellor 1988a, b). In other words, the sustainability problem in agriculture arises out of different socioeconomic circumstances and activities in the developed and developing countries. While lack of capital and access to inputs and technologies have had adverse environmental effects in the developing countries, it is the excessive use of some otherwise appropriate technologies and the inappropriateness of some costly inputs that have caused concern in the developed countries. Inappropriate technologies have caused environmental pollution, while very costly inputs are increasingly rendering agricultural production uneconomical in the absence of subsidies.

Rodale (1988) has cited the following reasons for the current interest in sustainability in agricultural production:

- problem of high productivity and surpluses, associated with a concern about whether these could be kept up;
- as nonrenewable resources are the basis of operation and productivity of conventional American agriculture, it is feared that when supplies run out either food will become too expensive or productivity will decline;
- high levels of production today contributing to environmental degradation, in terms of soil erosion, degradation, and deforestation;

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- escalation of pollution problems traceable to some agricultural practices;
- concern about finding ways to rely more on internal farm resources and continuously enhancing them under rapid population growth and increasing pressures on the limited resources available;
- the likely unsustainability of conventional technologies and agricultural production systems in the future when agricultural production becomes the main source of energy and chemical feed stocks;
- problem of whether the good life in rural areas can be maintained if family farms are replaced by large-scale industrialized farms which produce all the food.

It is because of this concern about the environment in all parts of the globe and the fact that some human activities threaten human life-support systems that the World Commission on Environment labeled its report "Our Common Future". Mellor (1988a) has aptly observed that "now a beneficial partnership between rich countries and poor might pursue our common environmental goals," but he also wondered "whether the quick succession of developmental fads in the past two decades suggests that present environmental concerns may also fade away," leaving in its wake "wasted money, wasted time and lost momentum." In this regard, sustainability is now topmost in the agenda of priorities in the Consultative Group on International Agricultural Research (CGIAR). The World Bank and foreign assistance and agricultural development agencies are also according priority to sustainability. In the past, whenever such developments took place, African governments usually followed suit with plans and targets, but in the end success eludes us, as the Green Revolution has so far done.

Set against this background, the rest of this lecture will discuss the scope of activities involved in the development of sustainable systems necessary for effective agricultural development in Africa. Due consideration is given to the resources available for agricultural production and research, their efficient management in the diverse ecological conditions of the continent, and the organizational and institutional factors that ensure sustainability. Finally, the roles of international agricultural research centers (IARCs) and national agricultural research systems (NARS) are reviewed, and recommendations are made for the achievement of objectives through effective interdisciplinary and institutional cooperation. Many of the concepts about sustainability presented here are not new. What may be different is their interpretation and the discussion on various factors that affect sustainability from the African and an agronomist's point of view.

Problem of Definition and Conceptual Framework

As a more or less abstract phenomenon dealing with complex and practical problems of agricultural production, the dictionary definition of sustainability as the continuity of a process, activity, or achievement of results without failure or decrease does not give a concrete indication of the real nature of the term as applied to agriculture. The BIFAD (1988) task force report on strategies for sustainable agriculture gave the following definitions from different sources:

- The successful management of resources for agriculture to satisfy changing human needs, while maintaining or enhancing the natural resource base and avoiding environmental degradation.
- The ability of an agricultural system to maintain production over time in the face of social and economic pressures.
- One that should conserve and protect natural resources and allow for long-term economic growth by managing all exploited resources for sustainable yields.

The first of these is the same as the CGIAR/TAC (1988) definition of sustainable agriculture. Dover and Talbot (1987), while noting that sustainability means different things to different people, defined sustainable agricultural systems, based on ecological principles, as *those systems whose productivity can continue indefinitely without undue degradation of the other ecosystems*. This definition does not address off-farm activities or externalities, which may also make agricultural systems or some factors of production unsustainable.

Rodale (1988) regards a sustainable agricultural production system as one in which the resources used in production are managed in such a way that they are more or less self-generating and ensure continual improvement well beyond conventional expectations. This implies that prevailing agricultural production systems are not to be regarded as sustainable. Knezek et al. (1988) defined sustainable agriculture as one which is

- resource conserving and uses external and internal resources as efficiently as possible,
- environmentally sound, actually enhancing rather than detracting from the natural environment, and
- economically viable in that it earns a fair return on farm investments.

It is interesting to note that, in this definition, the earnings are not necessarily maximized or optimized. Sometimes, due to the concern about environmental implications, some part of the productivity may be conceded in order to ensure sustainability and because of the need to minimize undue exploitation of resources.

Lynam and Herdt (1988) stress that sustainability must have a precise definition and, after referring to Conway's (1985) definition of it as "the ability of a system to maintain productivity in spite of a major disturbance such as is caused by intense or large perturbation," point out the implied emphasis on the time dimension in sustainability. They then observe that there is a problem of specifying the boundary level at which sustainability, defined mainly in terms of its characteristics, applies, noting that confusion arises from the mixing of levels. Furthermore, they define sustainability as *the capacity of a system to maintain output at a level approximately equal to or greater than its historical average, with the approximation determined by its historical variability.* While this definition is, by and large, correct from the analytical and quantitative standpoint as regards the assessment of sustainability, some of the seven propositions associated with it are questionable on the basis of certain agronomic, ecological, and sociocultural considerations. These are the propositions which (1) do not seem to take cognizance of the fact that certain component technologies, which under testing may result in sustainable productivity at the systems level, may still be individually inappropriate for ecological reasons; (2) limit conceptualization of sustainability to the systems level because it is the level at which sustainability can be most easily tested; (3) de-emphasize the importance of externalities of a sociological or cultural nature because they involve more of value judgements; and (4) insist on determining sustainability at the highest level and then proceeding downwards. In the real world in which researchers and farmers operate, in view of adverse short-term and/or long-term effects, (1) not all technologies that can contribute to system sustainability are appropriate because the system may have adverse effects within and outside agriculture; (2) sustainability issues in an increasingly interdependent world and a global economy have global, regional, national, and local dimensions with sociopolitical, ethical, philosophical, and legal implications that are neither yet amenable to quantitative analysis nor a priority in the mandates of IARCs; and (3) sustainability should be assessed both downward and upward in the hierarchy of subsystems and systems, since synthesis and testing are usually preceded by assessment of components. The problem of sustainable agricultural production systems in Africa concerns a hierarchy of systems, since sometimes a sustainable production system at the local level may fail, for example, under invasion by swarms of locusts, for which action above, at the national or regional level, is imperative.

In this paper, a sustainable agricultural production system is defined as one which *maintains an acceptable and increasing level of productivity that satisfies prevailing needs and is continuously adapted to meet the future needs for increasing the carrying capacity of the resource base and other worthwhile human needs.* Sustainability can only be achieved when resources, inputs, and technologies are within the capabilities of the farmer to own, hire, maintain, and manage with increasing efficiency, to achieve desirable levels of productivity in perpetuity with minimal or no adverse effects on the resource base, human life, and environmental quality. It is doubtful whether any prevailing agricultural production system can be claimed to have achieved absolute sustainability and to have managed continuous increases in productivity without some economic, social, and/or ecological cost to the farmer or community in the short or long term. In other words, a sustainable agricultural production system is one in which the farmer continuously increases productivity at levels that are economically viable, ecologically sound, and culturally acceptable, through the efficient management of resources and orchestration of inputs in numbers, quantities, qualities, sequences, and timing, with minimum damage to the environment and danger to human life. Viewed in another way, sustainable agriculture as a bioeconomic activity remains a science, a business, and an art of managing resources and inputs in ways that ensure productivity at levels that satisfy changing human requirements. Implicit in this is a complementarity among the scientific (knowledge and technology), socioeconomic, and artistic elements. Here the art includes some tangible and some intangible—not easily quantified—cultural elements that do somehow contribute to sustainability. The resources, inputs, or technologies involved include all those that are required during all stages of production and those of the food system, up to the consumption stage. Therefore, seriously speaking, sustainable agricultural production can best be evaluated by the final nutritional impact and effect on farm income. Its evaluation criteria should include effects on human nutritional status and health, in addition to the extent to which the resource base is enhanced on both short-term and long-term criteria. This remains so, even though some components may be difficult to measure. Productivity over time alone should not constitute the criterion for measuring sustainability, if human life is endangered. Moreover, total productivity should actually be based not only on the economically consumed or marketed part but also on the total biomass, to the extent that it is known to be of benefit to man, livestock, and resource enhancement.

At the systems level, an agricultural production system is location specific, and it is uniquely determined on the basis of interacting physicochemical, biological, technological, managerial, and socioeconomic elements that satisfy specific objectives. In a sustainable agricultural production system in a given location, there should always be increasing knowledge, skill, and understanding of:

- **the physicochemical factors,** such as soils, climate, moisture, radiation, day length, etc., and the way they change and interact so that they can be manipulated or given due consideration in efforts aimed at creating favorable conditions for the
- **biological elements** of the production system in terms of crops and/or animals whose products are required in relation to their interaction in the agroecosystem with weeds, pests, and even beneficial and nonbeneficial organisms that shape their environment on the basis of
- **changing and appropriate technologies** at the disposal of the farmer, and acceptable and relevant to his circumstances on the basis of his
- **sociocultural background,** in relation to education, experience, community organization, social relations and institutions, legal systems, etc., to the extent that they interact compatibly to determine the
- **economic viability and ecological soundness,** based on the farmer's managerial ability and operational cost effectiveness, market and pricing structure, trade-offs with respect to maintenance of environmental quality, prevailing infrastructure, and policy environment. (Of course, the measures that ensure long-term sustainability may be unattractive in the short term to the farmer, in which case certain technology characteristics or state policy may be used to achieve the desired objective).

It should, however, be emphasized that, by and large, a sustainable agricultural production system should still be based on sound economic principles and should not necessarily be a low-input production system. According to Holt (1988), the development of economically viable agricultural production systems should be based on research aimed at selecting one or more production systems from among several alternative systems, which evaluate the optimal combinations of inputs, in such a way that the lowest cost of input per unit of output is achieved often at the point of maximum economic yield (Figure 1). Usually the higher the price, the higher the cost of production at which maximum profit or minimum loss is achieved, until the law of diminishing returns is encountered. The total variable cost of inputs can be reduced by using lower levels of inputs, and it does not always result in reduction of the variable costs per unit of output (Figure 1). Where the reduction in the level of a certain output and its cost causes the output to decrease, the fixed cost per unit of output usually rises. Research may provide the appropriate solutions, through the substitution of inputs with alternative, less expensive, but similarly effective inputs or through cost-reducing technologies. In the development of sustainable agricultural production systems, inputs and technologies whose combinations are used at various levels may not always be those that minimize loss and maximize profit. Where there is a trade-off between maximizing profit and minimizing losses, without serious adverse effects on environmental quality, the yield or productivity trends can be maintained at a reasonably positive rising slope. In any case, since a reduction in level of input usually results in low output, the level of productivity achieved may not satisfy demand, even though the economic levels of output may be achieved where, for example, the land resources are poor, marginal, and of low productivity potential. Thus, while low-input systems may be developed for poor farmers who cannot afford costly inputs such as fertilizèrs, they may not always be sustainable in the sense of satisfying increasing demands under increasing population pressure. But reduction of fertilizer cost through biological processes, in combination with reduced amounts of inorganic

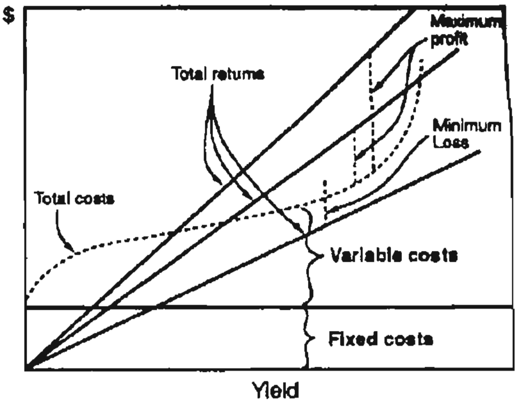


Figure 1. A graphic model of costs and profits associated with productivity goals (Holt 1988).

fertilizers and technologies that reduce labor costs, may constitute a viable alternative. In some situations, areas that are marginal for food or arable crops may not be as marginal or require high input levels for tree crops, which may yield higher incomes while enhancing the resource base. Thus, various options for achieving sustainability, through alternative resource management strategies generated by research, should be considered, together with the associated socioeconomic and institutional problems.

Development may be defined in terms of its biological context as a continuous process by which whole organisms or their parts grow in number and size, and differentiate and modify their chemical composition and physical structure during different stages of maturity or aging. Of concern here is the development of sustainable agricultural production systems in Africa through research, training, and related activities that facilitate widespread adoption by farmers. This kind of development entails the planning, designing, and evaluating of technologies, alternative subsystems, and systems on research stations and on the farmers' fields. Usually, on-station research involves choices of treatments, equipment, designs, practices, or other technologies to be tested on the basis of a reasonably good understanding of the farmers' overall environment, enterprise, and the on-farm and off-farm constraints to increased productivity.

Evaluation of results of on-station research leads to a few promising potential technologies and subsystems that are then modified through interaction with the farmer in the planning and design stage of on-farm research, in order to ensure their relevance to the farmer's needs and circumstances. The evaluation of on-farm adaptive research involves monitoring the adoption process, including the difficulties the farmer experiences in this process and the advantages of the technologies under test, so as to facilitate feedback to research station scientists and to determine the modifications needed to tune the technologies more finely to the farmers' circumstances and needs. The basic objective in linking on-station research and on-farm adaptive research is to determine the resource management decisions and input mixes that the farmer should use to create favorable environmental conditions for the biological development of organisms which constitute the commodities being produced on the farm. A favorable environment is one that enhances high yields and economic returns at the stage when the economic component of the commodity is harvested. In the development of sustainable agricultural systems, various environmental factors and commodity performances are evaluated within a sustainability perspective that should, as far as possible, not be limited to the productivity factor.

It is obvious that the development of sustainable agricultural production systems involves more work and a wider scope of activities, and of design, analytical, and evaluation capabilities, than have been needed in conventional agricultural research to date. It calls for a more holistic or systems approach and for monitoring of performance over a longer period of time than has been the practice so far. This also necessitates the use of evaluation criteria in which a sustainability perspective is incorporated. According to Francis et al. (1986), in the development of a sustainable or regenerative agricultural production system, emphasis is given to the use of resources found on the farm, instead of expensive imported energy resources, especially fertilizers and pesticides. In other words, priority is given to the farmers' reliance on internal farm resources as far as possible. The main objective is to limit the farmers' use of inputs that are normally not accessible. Harwood (1983) has noted that a conceptual framework for productive systems should include: (1) the interrelatedness of all parts of a farming system, including the farmer and farm family; (2) the importance of the innumerable biological balances in the system; and (3) the need to maximize desired biological relationships in the system, and to minimize the use of materials and practices which disrupt those relationships.

Francis et al. (1986) also observed that several studies of reduced energy, resource-conserving, sustainable production practices have been conducted and the economic consequences of adoption determined. They recommended that in these studies the biological and the economic components should be integrated by progressive biological sequencing to facilitate the choice of cultural practices that can cause a dynamic change in the production environment. Some aspects of this approach will be referred to later. Rawlins (1988) also emphasized that priority should be given to the application of systems science in the development of sustainable agricultural production systems and observed that today's complex problems cannot be solved unless people work together:

> But working together on large complex problems is not easy. Our "rugged" individualist heritage leaves us with ineffective tools to deal with problems that can only be solved by community action. Look at any really large system and you will find a tragic waste of resources resulting from failure to develop holistic management strategies that provide the necessary linkage between the systems components. Our failure to develop a sustainable food system is partly the result of compartmentalized thinking. Someone else has responsibility for agriculture. Others are concerned about the relative competitive advantage of one geographic area over another. Rarely are the needs of those who will live in the future represented fairly in the bidding process for the depleting resources we are spending. Scientists generally identify with one of these groups and assume the task of solving the problems presented by it. Rarely do we assume the responsibility of identifying, stating, and solving the problems presented by something as large as the

> food system as a whole ... This failure to look at whole systems results in piecemeal planning that fails to consider three important dimensions of real systems—and, consequently, permanently cripples the system. A holistic system must be treated as a single entity from a functional perspective, a geographic perspective, and a time perspective. Without taking into account potential trade-offs between functions and locations or without considering the full life-cycle of the system, decisions will be made that permanently fix the system's overall operating efficiency below the optimum.

Rawlins further noted that "powerful new tools for stating problems and linking interdisciplinary teams together to solve problems are beginning to emerge from the fledgling discipline of systems engineering and its allied fields." It is, therefore, important that in research aimed at development of sustainable agricultural production systems, teams of researchers must be managed in such a way as to ensure really intimate interaction among all relevant disciplines involved in as holistic a manner as possible.

Global Socioeconomic Considerations

In addition to the obvious scientific, technical, and economic issues that are involved in the development of sustainable agricultural production systems, there are several other factors crucial in ensuring sustained development, the understanding of which could engender more national commitment to peace and stability and enhance allocation of resources and priority to sustainable agricultural research and development activities. Some of these factors also determine scientists' attitudes and effectiveness in related research, development, and training activities that enhance farmers' adoption and use of the practices and systems developed. These issues are sometimes ethical, metaphysical, political, legal, philosophical, and religious, but mostly cultural in nature. They may not be considered important by most professional agricultural economists and agronomists, especially in developed countries. If I am not mistaken, I think some of these constitute what Lynam and Herdt (1988) referred to as externalities. As Ruttan (1988) observed, "The first post-war generation of development economists gave a prominent role, at least at the rhetorical level, to the role of cultural endowments in constraining or facilitating economic growth."

There has recently been a spate of publications on these or related issues and some of them are briefly reviewed here. Others, which require more detailed study, include: Alexander (1977), Lovelock (1979 and 1988), Gabel (1979), National Forum (1988), American Journal of Alternative Agriculture 1(1 and 2, 1986), Barnaby and Pearson (1988), The Hunger Project (1985), World Resources Institute (1988), Mellor (1988b), Byron (1988), Rome Forum (1986), Davis and Schirmer (1987), and Jacobs (1981). Lovelock's Gaia hypothesis (1979 and 1988) views the world as a self-regulatory or closed system, which operates in such a way that the interaction of all the mineral, biological, and other nonliving elements creates conditions suitable for life. His concept of the role of evolutionary diversity in the self-regulation of conditions on earth constitutes a sound basis for understanding the role of diversity in maintaining sustainability.

Barnaby and Pearson (1988) reviewed world events and the progress towards evolution of a global economy and concluded that there were no signs of war in the world until about 5000 BC, but from that time up to World War II and today, problems of territory and resources, ideology, armed camps, new identities, politicians, etc., have always constituted the roots of conflict among nations, with the inequalities between developed and developing countries as a very serious problem. They recommended that priority should be given to the following issues in ensuring peace and sustainable development:

> *Steady State flow* by ensuring that the real wealth of the earth or capital in terms of fertility of soil, diversity of species, clean water and air, and equitable climate are guarded and replenished. Energy for life, which entails tapping of fuelwood, solar power, photovoltaics, biomass, and other forms of energy efficiently.
>
> *A new environmental concern*, which, in a sustainable society, calls for all people to regard protection of the environment as a healthy insurance for the future.

Redistribution of wealth, which is necessitated by the fact that poverty is a major constraint to progress now and in the future. Therefore, this should be in the agenda for sustainable development.

Appropriate technology, which deemphasizes accelerated and destructive use of resources.

Participation in conflict resolution, through a broader base of power, more cooperative forms of government, better ways of conflict resolution.

Education of people, which is necessary for continually acquiring knowledge and developing skills to achieve many of our objectives in development.

Decentralized economy, involving restructuring the economies through greater involvement of regional and even local centers rather than their being centralized in industrial countries at New York, London, or Tokyo.

Moral controls on technology, especially as regards the development of military technology and predicting with care its likely consequences. The world's military expenditure is estimated at US$100 billion annually (Barnaby and Pearson 1988). This amounts to about US$2 million a day (Swaminathan 1988). African countries spend US$25-750 per capita per annum on defence (Barnaby and Pearson 1988). At least 8 African countries spend more than 20% of their central government expenditure on the military, while several others spend in excess of 10% (see pp. 33-34). The annual expenditure on arms by African countries amounted to about US$14 billion in 1982. Yet almost all African countries do not command sufficient funds for research and development activities that are vital in increasing agricultural and industrial productivity. There is, therefore, an urgent need for new attitudes which moderate national sovereignty and global loyalties.

Spread spiritual revolution, limiting abuse of power and encouraging a new leadership to abolish war.

The World Commission on Environment and Development (WCED), commissioned by the United Nations to draw up a global agenda for action, reviewed several recent events of environmental significance and noted that the "earth is one but the world is not. We all depend on the biosphere for sustaining our lives. Yet each community, each country, strives for survival and prosperity with little regard for its impact on others." (WCED 1987)

The WCED report drew up the following objectives and requirements for sustainable development:

A. Objectives:

- reviving growth;
- changing the quality of growth;
- meeting essential needs for jobs, food, energy, water, and sanitation;
- conserving and enhancing the resource base;
- reorienting technology and managing risk; and
- merging economics and environment in decision-making.

B. Requirements for Sustainable Development:

1. a political system that secures effective citizen participation in decision-making;
2. an economic system that is able to generate surpluses and technical knowledge on a self-reliant basis;
3. a social system that provides for solutions for tensions arising from disharmonious development;
4. a production system that respects the obligation to preserve the ecological base for development;
5. a technological system that can search continuously for new solutions;
6. an international system that fosters sustainable patterns of trade and finance; and
7. an administrative system that is flexible and has the capacity for self-correction.

The Hunger Project (1985) discussed various kinds of hunger and emphasized that although hunger affects millions and causes 13-18 million deaths per year, only when it occurs in a form as dramatic as famine does it become news. It noted that in efforts to eliminate hunger, myriad problems are encountered: economic, social, ideological, political, philosophical, cultural, and even psychological in nature. The report concluded that issues which determine the persistence of hunger include population, food, foreign aid, national security, and the new international economic order.

Byron (1988) discussed ethical issues in the protection and promotion of the right to food and observed that "each person, in function of being human, has a right to those material necessities without which human life and human dignity cannot be sustained." "One of these necessities," he noted, "is food, but the unfettered, individualist exercise of human rights and unregulated play of free markets are in no small way responsible for the problem of world hunger," when viewed in relation to the social responsibilities of human communities. Byron cited the Charter of the United Nations as affirming a "faith in fundamental human rights, in the dignity and worth of the human person, in the equal rights of men and women of nations large and small." He further noted the United States House-Senate Concurrent Resolution declaring as National Policy the right to food and affirming that, "every person in this country and throughout the world has the right to food—the right to a nutritionally adequate diet—that this right is henceforth to be recognized as a cornerstone of U.S. policy."

Byron further observes that the United States' Public Law 480 (Food for Peace), enacted in 1954 in a domestic political environment when there were huge farm surpluses, provides for food aid to support United States foreign policy and national security goals. Other observations on related issues made by Byron (1988) emphasize that

- the right to food does not depend on employment performance;
- protection of the right to food extends to protection of natural resources, land, water, plant, and animal species;
- society has an obligation to encourage the research talent needed for this task, and to develop it, reward it, and recognize it;
- in this ethically sensitive world, the realization that everybody possesses the right to a nutritionally adequate diet should fasten the attention of scientists, economists, and politicians on the hunger in the community;
- the problem of the right to food should be addressed at community, national, and international levels;
- the political will for assuring the right to food requires that various measures, including taxes, be taken to alleviate hunger;
- causes of hunger include considerations about geography and climate, resource abuse, population, poverty, politics, trade barriers, colonial legacy, and unequal distribution of wealth and income in the world;
- the complexity and consequent neglect of agricultural development in many parts of the world have resulted in a failure to establish a workable system of grain reserves.

Finally, Byron (1988) insists that the consideration of political means of eliminating hunger and assuring the right to food should be accorded a global perspective, transcending national boundaries. He regrets that despite the stated policy of the United States government, figures on the U.S. regional allocations to foreign assistance in 1977 to 1986 indicate that political and military considerations are given priority (Table 1, which also shows that more funds are allocated to foreign assistance in the Middle East, Europe, Asia, and Latin America than to Africa).

Mellor (1988b) regards it as an assault on the ethical standards, fairness, and justice of Americans that (1) farmers in America are paid to reduce food production, while at the same time uneconomically large surpluses are held at high cost when people in developing countries are suffering from hunger, and (2) scientific capacity for food production is lacking in food deficit countries and is excessive in food surplus countries. He observes that the continuing inconsistency between ethical principles about food production and the reality of food needs in developing countries is due to political and technical reasons. The technical reason arises from institutional difficulties in transferring food from one country to another with poor facilities for movement. The political reason is related to the problem of whether developed countries are really committed to meeting the needs of poor

Table 1. Regional allocation of U.S. aid: 1977-86.

Region	Annual allocation in constant dollars (millions)							
	1977		1980		1983		1986	
Latin America	689	(6.8)[1]	711	(7.9)	1,474	(12.0)	1,714	(14.5)
Asia	2,209	(21.7)	1,656	(18.4)	1,864	(15.2)	1,840	(15.6)
Middle East	5,488	(53.9)	4,394	(48.8)	6,029	(49.2)	5,475	(46.4)
Europe	1,078	(10.6)	1,115	(12.4)	1,745	(14.2)	1,843	(15.6)
Africa	724	(7.1)	1,122	(12.5)	1,149	(9.4)	919	(7.8)
Total assistance	10,187	(100.0)	8,998	(100.0)	12,261	(100.0)	11,791	(100.0)

Source: Byron (1988) who cites the Select Committee on Hunger, U.S. House of Representatives (November 1986)

1. Figures in parentheses are percentages for each year indicated.

countries, since policy and action depend more on narrow concerns of national self-interest than on ethics. There is also the fact that humanitarian organizations do a lot to provide food for the poor in time of need and, sometimes, the developing countries are concerned about the adverse effects of food aid on local food prices and domestic production. Mellor calls for priority to be given to scientific research to increase productivity, income, and employment, while at the same time taking action on the redistribution of scientific research resources in the world to reduce the monopoly by developed countries.

Of relevance in considering the political, ethical, and socioeconomic implications of agricultural development through the support of agricultural research in developing countries by foreign assistance from developed countries are three recent papers by Mellor (1987), K. Anderson (1987), and Jacobs (1981). Mellor (1987) emphasizes the need for developed countries to be committed to supporting developing countries through investments in research and rural development, since this usually results in increased income and more employment opportunities. He argues that the increase in food output in developing countries does not generally reduce food imports at early stages of development when the contribution of agriculture to GDP and the demand for food are high. Consequently, the usual fear by farmers in Australia and developed, food-exporting countries that foreign aid in support of agricultural research threatens their market for basic staples is unfounded.

K. Anderson (1987) similarly observes that the fear that agricultural growth in developing countries reduces their agricultural imports and is consequently against the interest of agricultural exporting countries, such as Australia, is unfounded. He argues that when due consideration is given to the effects of technical assistance in agricultural research on developing countries' agricultural supply, increased per capita income, and demand for agricultural and other products, such assistance may be beneficial to the donor for several reasons. Firstly, such assistance to developing countries is motivated not just by economic benefits from trade expansion but also by humanitarian reasons. Secondly, benefits may accrue to the donor as well as the developing country, where the financial assistance to increased food production results in the processing and marketing of agricultural products. Finally, foreign assistance may engender political stability, with related desirable results.

It is often not appreciated by African leaders that donor countries face political pressures at home to curtail foreign assistance to developing countries because of the fear of competition and reduction in agricultural trade, and that donors may also have political reasons for providing or not providing assistance to agricultural research and development programs in developing countries when this is against expressed government policy. Such an appreciation would make many of them realize that sustainability of support to research and development in agriculture cannot always be guaranteed when they plan to obtain a large proportion of such resources from donors through foreign aid.

Jacobs (1981) also discussed moral and ethical issues in exploitation of the tropical rain forests, and he quoted passages based on the Bible, which gave man the right over all other organisms. It is observed that until recently no one has seriously questioned this claim of man's power over nature. Routley (1980) is quoted as having observed that "it is not possible to provide criteria which justify, in the sharp way standard western ethics do," the division "between humans and certain other non-human creatures." The point is made that while hunter/gatherers and often indigenous peoples in the past utilized the forest in a more sustainable way as the source of numerous products, now these forests are exploited mainly for timber from a few species. Since colonial times, many of these operations have been centralized, and the trend continues even after independence because forest policy is decided in the capital city. The exploitation, plunder, and corruption continue as, for example, in Indonesia, where Japanese, South Korean, Taiwanese, and Italian companies have been awarded concessions to continue their operations.

Failures in following established ecological guidelines for forest management have been noted, and the damage done by man to nature in the name of development activities documented by Thomas (1956), Farvar and Milton (1972), and Eckholm (1976). It is also noted that even in foreign aid and technical cooperation development projects, a considerable amount of environmental damage is allowed to be perpetrated by immense financial and political interests. It would appear that development now gives priority to the exploitation of natural resources for immediate profit, with no concern about the future and the adverse effects.

Several publications stress the need for a more global outlook in sustainable agricultural development, and for changes that reflect the trend towards greater interdependence and a global economy (Swaminathan 1988, Rome Forum 1986, IMC 1988). The Rome Forum report stressed the need for sustainability in agriculture to be given priority from a global viewpoint, aimed at sustainable food security. It stressed that efforts to achieve this should blend (1) the universal features arising from basic human rights and obligations, and (2) the unique features that cater for specific cultural, economic, and ecological conditions, among countries and within different regions in the same country. It stressed that there should be no compromise in the basic principles on

- sustainable livelihood security;
- national and international economic policies that influence agriculture and related activities to be based on principles of long-term economic and ecological considerations; and
- government to promote participation of farmers in formulating and implementing agricultural development plans.

The Forum called for the restructuring of institutions to ensure a higher degree of horizontal coordination among diverse activities in land use, water supply, and management, in addition to providing for people's participation. Other recommendations listed include the need for

- a farming systems perspective;
- more knowledge-intensive farming systems;
- greater care in choice of technologies; and
- a priority program for Africa.

All these indicate a growing interdependence in the new world economy and the need for developing and developed countries to work together. As Braverman (1988) concluded "selfishness and lack of vision in the short run may result in long-run regret for all parties. This challenge in cooperation, in particular in its agricultural domain, is the noblest cause for our species, since by sharing burdens and distributing economic power, we also may eliminate hunger and starvation from the face of the earth."

Braverman (1988) observed that during the last 25 years, tremendous changes have converted national economies, linked in the past by relatively small amounts of international trade, into fully integrated international capital markets. These changes were, in turn, the culmination of major technological changes in (1) communication and information transfer, including the computer and satellite technologies, and (2) new fast transportation technology, all of which have not only made instantaneous financial transactions possible but have also rendered movement of goods and services from one part of the world to another very rapid. These major changes, their implications on developing countries' agriculture, and the actions needed to stabilize the world economy, so as to usher in an era of agricultural growth in developing countries, can be summarized as:

- Greater integration of national economies than in the past, making them more dependent on trade and thus more open to the forces of the international economy. The overall result is that national economies are much less influenced by domestic policies.
- Change from a fixed exchange rate to a system of block floating since 1973, so that changes in monetary policy in the United States that affect interest rates also cause changes in competitive export sectors in foreign markets, with agriculture as the trade sector bearing the burden of adjustment to changes in domestic monetary and fiscal policies and thus experiencing large shocks when the two policies contradict each other.
- Marked increase in monetary instability, which has increased adjustment problems in domestic economies, with the result that countries undergoing adjustment to lower exchange rates are marketing commodities at lower prices but experience high import prices, which often make it difficult to obtain the inputs needed to sustain agricultural productivity.
- The international debt crisis of the 1980s in developing countries, resulting from a misguided urge to recycle surpluses from petrodollars by borrowing on easy terms. These very heavy debt burdens of developing countries also reflect the impact of the U.S. domestic monetary policy on other countries, and the fact that lack of coordinated monetary and fiscal policies causes instability in exchange rates with very adverse effects on agriculture, which then fails to function as the engine of growth in developing countries.
- Trade barriers and subsidization of agriculture in the United States, Japan, and the European Economic Community, which has resulted in low commodity prices, thus shifting terms of trade against commodity prices in developing countries.
- The need for developing countries to reverse an urban-bias in price, trade, and investment policies and coordinate it with appropriate domestic macropolicies and reforms in marketing and distribution, so as to offer adequate price incentives to farmers and boost production and marketing of export crops and major staples sold locally.

That review is by no means exhaustive, but serves to confirm the widespread concern about environment and sustainability in all aspects of resource management and development activities. Nearly all of those viewpoints call for a change of attitudes and ethics, which Gabel (1979) defined as "the acknowledgement of interdependence". With this background on global aspects of sustainability, it is in order to focus on the African problem.

Many of these issues are not on the research agenda of the IARCs, but they serve to emphasize the greater role national institutions have to play in sustainable agricultural development. They also serve to emphasize the need for the CGIAR to give a higher priority to finding ways for communicating with African heads of state and/or policymakers at regular intervals of at least once a year. This can be done through a special presentation to policymakers, which could be arranged under the auspices of the Organization of African Unity/Scientific and Technical Research Council (OAU/STRC).

As an Adviser to IITA, the former Head of State of the Federal Republic of Nigeria General Olusegun Obasanjo (Rtd) can play a more specific and effective role in facilitating such dialogue and information transfer. Where African policymakers have a better understanding about the global, regional, and national implications of sustainability, they will be more effective in formulating policies and determining priorities in agricultural research and development.

Scope and Complexity of Sustainability Issues

A reference to Davis and Schirmer (1987) clearly shows the complexity and the wide range of topics that are considered under sustainable agriculture. These include (1) sectoral activities, such as agriculture, forestry, fisheries, and livestock; (2) resource management issues, dealing with soils, land, natural resources, and watersheds; (3) environmental problems, such as desertification, soil degradation, salinization under irrigation, and loss of genetic diversity; (4) institution building and human resources capacity development; (5) roles of government and the private sector; and (6) agricultural research, extension, and information management. All these strongly indicate that sustainability in agricultural production and development impinges on various aspects of natural resources and environmental management and calls for a multidisciplinary approach, necessitating interaction among physical, biological, and socioeconomic disciplines in planning, policy formulation, and research and development activities.

Idachaba (1987) identified four sources of lack of sustainability at different levels, including (1) national macroeconomic and political environment; (2) the world economy; (3) the agricultural sector, and (4) interaction between the agricultural sector, the macroeconomy, and the world economy. Lack of sustainability in growth was seen, for example, to produce adverse effects at household, community, and food-dependent urban population levels. Disruption of foreign exchange at the national level frustrates national development activities, creates uncertainty, and results in lower investment in agriculture. Policy issues affecting sustainability include (1) the role of government through parastatals or nationalization in agricultural production and development activities; (2) problems of political instability and their effects on sustainability, as reflected in frequent changes in political and administrative leadership at the federal and state ministry levels; (3) changes in institutional management of agricultural research and technology development; (4) frequent changes in exchange rates and their reflection on export crops, input costs and supplies, and the problem of barriers against entry into international markets of semi-processed agricultural products; and (5) the problem of rural infrastructure and rural-urban differentials, subsidies, and their effects on input supplies. Finally, it was observed that outbreaks of pests, diseases, and drought also affect sustainability of agricultural production, as well as its interactions with domestic and external factors.

The CGIAR/TAC (1988) report also recognized the importance of socioeconomic and legal factors in sustainable agricultural production. It noted the crucial role of political and administrative resources and policies; infrastructure, including markets; adequate input supplies and credit; institutions for education, research, and extension; and land tenure and appropriate or adequate laws and regulations in ensuring sustainability, even though the IARCs are not in a position to address many of these issues directly. The report also reviewed physical and biological determinants of sustainability, associated environmental hazards, contributions the IARCs are making in relation to sustainability, and current trends in production systems. Providing information on factors that threaten sustainability in various production systems being researched by the IARCs, and the way these sustainability problems are being addressed, the report made recommendations on what strategies the CGIAR has to adopt in dealing with these factors.

J.R. Anderson (1987) noted the significant role the IARCs are playing in increasing food production in developing countries and emphasized that agricultural research will continue to play its vital role in feeding the world in the year 2050 AD and beyond. He observed that 'easy gains' in agricultural production have already been made, but that (1) the growing concern about environment and sustainability, and (2) research to spur technological advances in difficult and diverse environments, call for more patience and longer-term investments. This is because the research agenda is greater in scope, complexity, and challenge and requires a longer time lag than the normal 10-20 years for a significant impact to be made. He pleaded that developed countries, such as Australia, have the moral duty to continously offer assistance to humanity with professional expertise and foreign assistance in support of agricultural research, which has been proven to yield significant returns in the developing world.

Territorialism and the Frontier Model: Background to African Agricultural Development

The concept of territorialism in animals has had a lot of influence in the biological and social evolution of man and other organisms, especially birds, fishes, and mammals. Certain aspects of territorialism are responsible for the ethical, political, and cultural problems being encountered globally and regionally in Africa today. Territorialism operates in such a way that individual animals or a group of them usually live in a fixed geographical area, and the individual or group is usually able to defend the territory against intruders. Outside the territory, the individual organism threatens the territory or territories of others and this may result in a lot of friction. The evolution of territory minimizes friction and aggression. Various aspects of problems of the territorial imperative in human societies are the cause of the moral, ethical, sociological or cultural problems in sustainable development.

The idea of territory is well developed in human societies with respect to land, home, and property, and it is the cause of fights among individuals or groups and, since civilization began, wars between or among nations. The territorial imperative in man is very well developed and usually follows the physical law that nature abhors a vacuum. Consequently, mankind exhibits a propensity for establishing territorial control over others not only geographically, but also in materials and property, ideas, ideology, management, and in various fields of opportunity where a vacuum exists. In mankind's struggles for territorial control of wealth, materials, ideas, etc., which give us power and influence over others, laws and codes of conduct exist only at the household and national levels. No such laws or codes of conduct exist that are universally respected at present at the international level. Even so, many environmental issues are not covered, and the possession of material wealth, money, and political power may give one the right to override any rules or codes that exist. For example, though a law of the sea has been passed by the United Nations, there are not many laws in resource and environmental management that are effectively enforceable by the international community. This is also the reason why, in the exploitation of natural resources worldwide, it is always difficult to control the behavior and activities of multinationals and other powerful vested interests, especially in environmental matters.

One may wonder how this is connected with sustainable agricultural development in Africa. The concept of territorial imperative has been known to operate in agricultural development since prehistoric times in many parts of the world, based on the moving frontier concept of Turner (1962). In this regard, the moving frontier is defined as the temporary boundary of an expanding society at the edge of substantially new lands. It is a concept developed in North America in relation to the western expansion of Europeans. But it operated locally between pioneer farmers and hunter/gatherers or pastoralists and cultivators in many parts of the world. Various events that may result at the end of the moving frontier are listed in Table 2. Alexander (1977) maintains that there is archaeological evidence of the end of the moving frontier in many parts of the world. Twenty-eight of these complexes have been discovered worldwide, and the six of them located in Africa consist of two in the temperate zone and four in sub-Saharan Africa (Table 3). It is rather interesting that in the more temperate areas, the one involving a

Table 2. **Consequences at the end of a moving frontier between farmers and hunter/ gatherers.**

Farmers	Hunter/gatherers
A. Partial migration to new region if new domestic plants and animals are available.	Isolation or development of state frontier.
B. Land seized from neighbors by warfare.	
C. Develop new farming technologies either for intensive use of existing, or for previously disregarded, land.	Further destruction or absorption.
D. Increased and specialized exploitation of wild resources.	Symbiotic relationships possibly established.
E. Voluntary restriction of population.	
F. Development of sociological devices for absorbing time and energy.	Isolation or development of static frontier.

Source: Alexander (1977).

Table 3. **Estimated end of the moving frontier between farmers and hunter/ gatherers in Africa.**

Agricultural complex	Region or Area	Estimated end of the moving frontier
A. Tropical Africa		
1. Tropical seed growing complex	a) Western savannas	2000 BC
	b) Eastern and southern savannas	1000 AD
2. Yam-oil palm complex	West and Central forests	2000 BC
3. Camel (pastoral) complex	West, semi-desert	1000 AD
4. Cattle (pastoral) complex	a) Western savannas	3000 BC
	b) Eastern savannas	1000 AD
B. Temperate Zone		
5. Wheat/barley complex	a) Mediterranean coast and Ethiopia	3000 BC
	b) Extreme south, subtropical zone	1900 AD
6. Cattle/sheep (pastoralism) complex	a) Central and southern Saharan fringes	3000 BC?
	b) Extreme south, subtropical zone	1000 AD

Source: Alexander (1977).

wheat and barley complex and a cattle/sheep/pastoralism complex occurred with the arrival of Europeans in South Africa about 1910 AD. While the Zulus and others were defeated then, the problems arising from this clash of territorial interests between South Africa and adjacent states continue to be a cause of destabilization in the area. In both Central and Eastern Africa, European settlements brought about some shifts and adjustments of the moving frontiers, and it is only after independence that measures have been taken to seek redress through land reform. Also, it is only in those areas in Africa that land reform through land redistribution has been successful, except in the case of countries like Egypt.

Before the coming into Africa of Europeans and of Islam, the moving frontiers had ended between a tropical seed-growing complex in Western Africa and hunter/gatherers in the savanna areas at about 2000 BC, and in eastern and southern savannas at about 1000 AD. The latter accompanied the spread of 'bantu' languages southward from West Africa. The end of the moving frontier occurred between a cattle pastoral complex and cultivators in the western savanna areas at about 1000 AD. This is the area now occupied by Fulani pastoralists after the Moslem conquest and in East Africa, the areas occupied by the Masai and other groups. The coming of Islam and the European intrusion into Africa and colonialism caused changes in the consequences of the end of moving frontiers, since intrusion of pastoralists into areas occupied by cultivators and vice versa, following the establishment of colonial control in many places, allowed movement of various peoples into areas previously barred to them. Even though there had existed symbiotic relationships among various groups within artificial boundaries created during the colonial era, two decades after independence, these changes still constitute the basis of friction among various incompatible groups, as a result of religious, ideological, ethnic, or other causes. It is, therefore, not surprising that because of these there has been marked political instability and military rule in 28 African countries, in addition to several wars, some of which continue to cause civil strife in Ethiopia, Northern Africa, the Sudan, Angola, Uganda, Mozambique, and Namibia, and refugee problems. Civil strife in Mozambique, Angola, and Uganda has led to neighboring, otherwise peaceful countries, such as Malawi, Zaire, and Tanzania, being saddled with 600,000; 338,000; and 266,000 refugees, respectively (U.S. Committee on Refugees, 1988). It is obvious that with such instability and associated problems, sustainable agricultural development would be hard to achieve in many areas of Africa.

This illustrates how political and anthropological problems, which cannot be addressed by agricultural research, may constitute stumbling blocks to sustainability. In such situations, research to increase and sustain agricultural productivity is impossible. In fact, one may venture to hypothesize that the basic sustainability problem in Africa is that of developing an innovative resource management strategy to deal with the problems created by the end of a moving frontier, where a conservation model of agricultural development has encountered the law of diminishing returns.

The frontier concept and territorialism fit very closely the models of agricultural development put forward by agricultural economists. Ruttan (1977) observed that the literature of agricultural economics features five general models:

- the frontier model;
- the conservation model;
- the urban-industrial impact model;
- the diffusion model; and
- the high payoff model.

These, according to Ruttan, should be supplemented with the induced innovation model.

As Figures 2, 3, and 4 show, the basic problem facing African agriculture today is that the end of the moving frontier at the individual household, village, or macro-urbanized town levels has reached the limit of increased productivity that the mainly biological innovations of the conservation model can contribute to satisfying higher demand from a growing population. The concentric conceptual framework approaches that of the von Thünen (1826) model, except that instead of the distance/price relationship between the rural farms

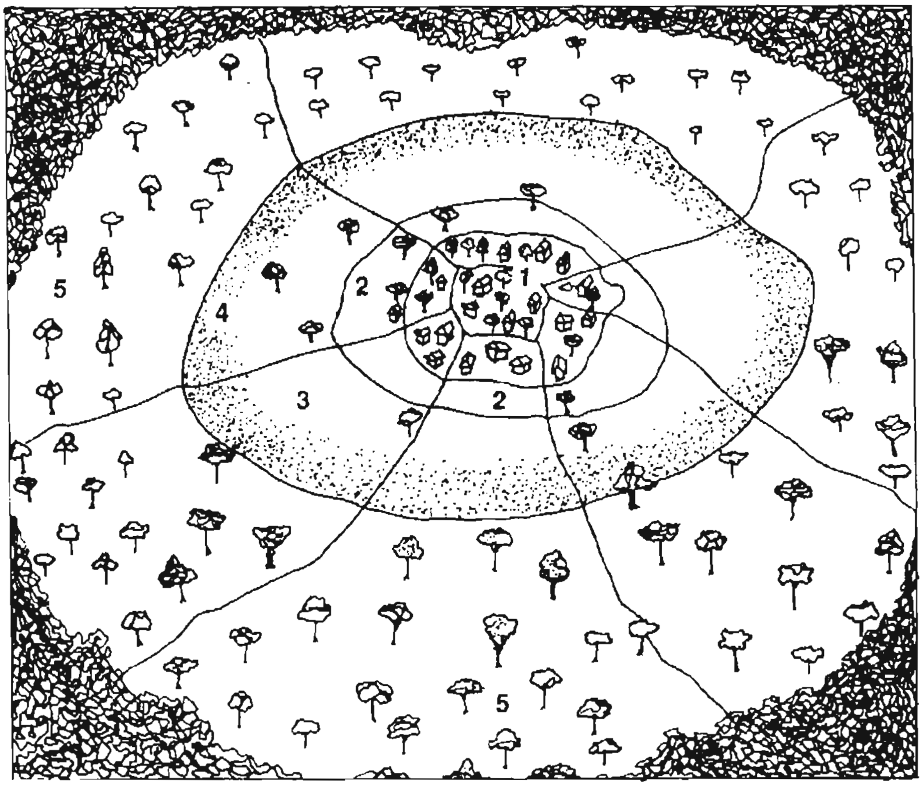


Figure 2. Spatial organization of land use in N'Gayene, Senegal (from Pelissier 1966): (1) houses and gardens, (2) permanent cultivation, (3) semi-permanent cultivation, (4) intensive shifting cultivation, and (5) bush and extensive shifting cultivation (after Ruthenburg 1971).

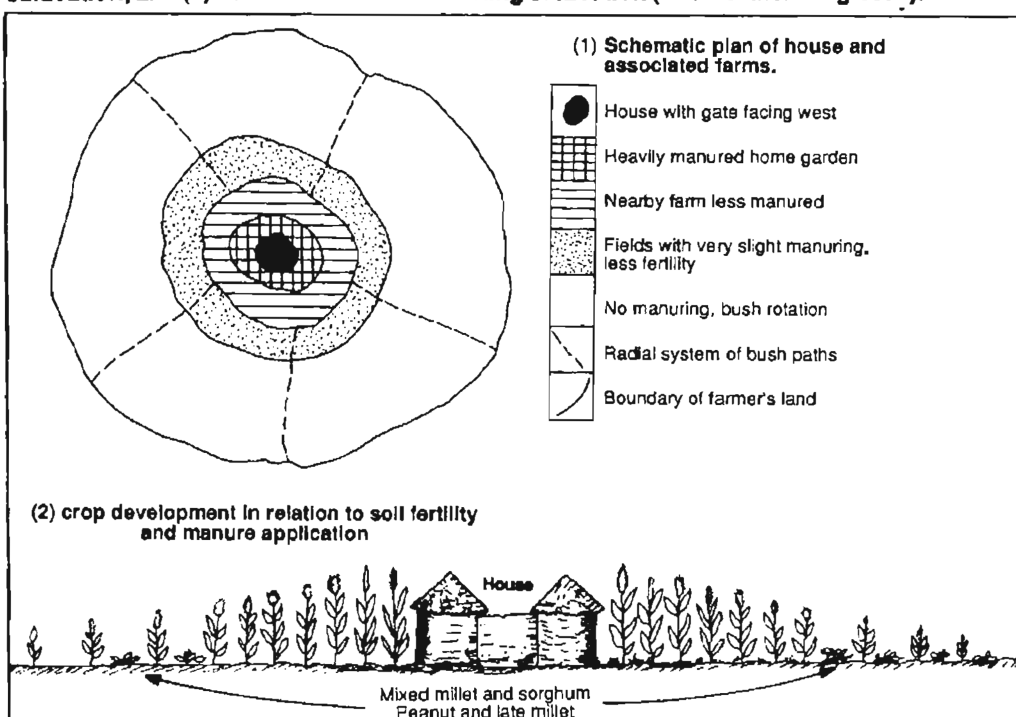


Figure 3. A house, home garden and associated cultivated fields in Nangodi, northern Ghana (after Hunter 1975).

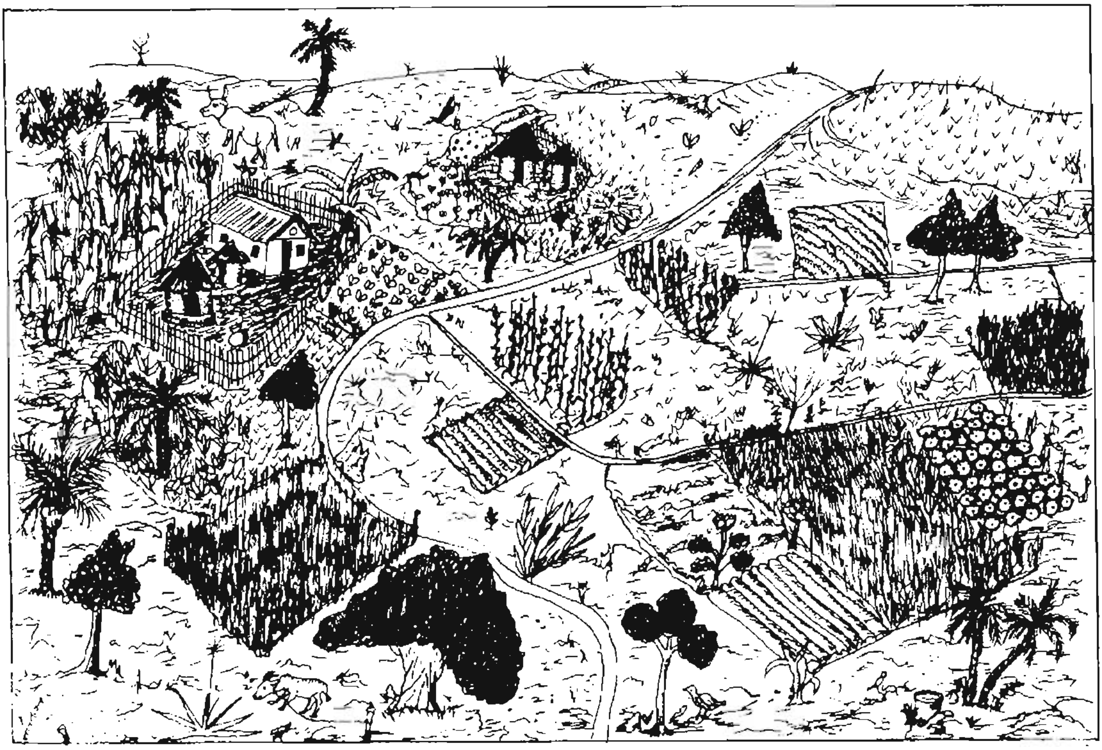


Figure 4. A typical rural landscape in the Savannah area of West Africa.

and urban markets, it is the problem of relationship between households and the location of input supplies. Population pressure intensifies land use and follows the trend of events postulated by Boserup (1965). Simply stated, it is a problem of how to increase input levels by utilizing inputs that are external to the farm or country and the lack of capabilities for commanding access to inputs or developing technologies that can reduce cost, achieve sustainability, and enhance the environment.

In this context, one of the basic problems of African agriculture is that it is practiced on highly fragile soils of low inherent fertility, where the biological processes of fertility maintenance, characteristic of the conservation model, constitute the main resource management strategy for increasing productivity, but there is a limit to its use in ensuring sustainability. The area of exploitation of resources that are concentrated in the home garden or are used to feed the household continues to expand, until it reaches the limit imposed by the law of diminishing returns, in response to demands of increased population pressure. The only solution is to use external inputs not available in the locality or country. But these inputs are still beyond what the poverty level can permit in facilitating farmers' access, as is the case with chemical fertilizers. Africans are still to develop alternative technologies that are cost-effective. Until now, this capability is simply not there.

In many parts of Africa, for example the Ukara Island in Tanzania, the Kano close-settled area and south-eastern Nigeria, high population densities of over 400 person per km^2 have been attained through the conservation model, based on intensive agricultural production systems, using organic manures and often also integration of crops and livestock. There is a dynamic cycling of materials and energy in such systems, as is shown in Figure 5. With increased population growth, however, there is increased pressure on the land, associated with considerably high levels of outmigration and reliance on nonagricultural activities to supplement low incomes. A considerable amount of labor goes into keeping the system going. If population continues to increase, unless other inputs, such as fertilizers and labor-saving devices, are introduced, the system might collapse as a result of

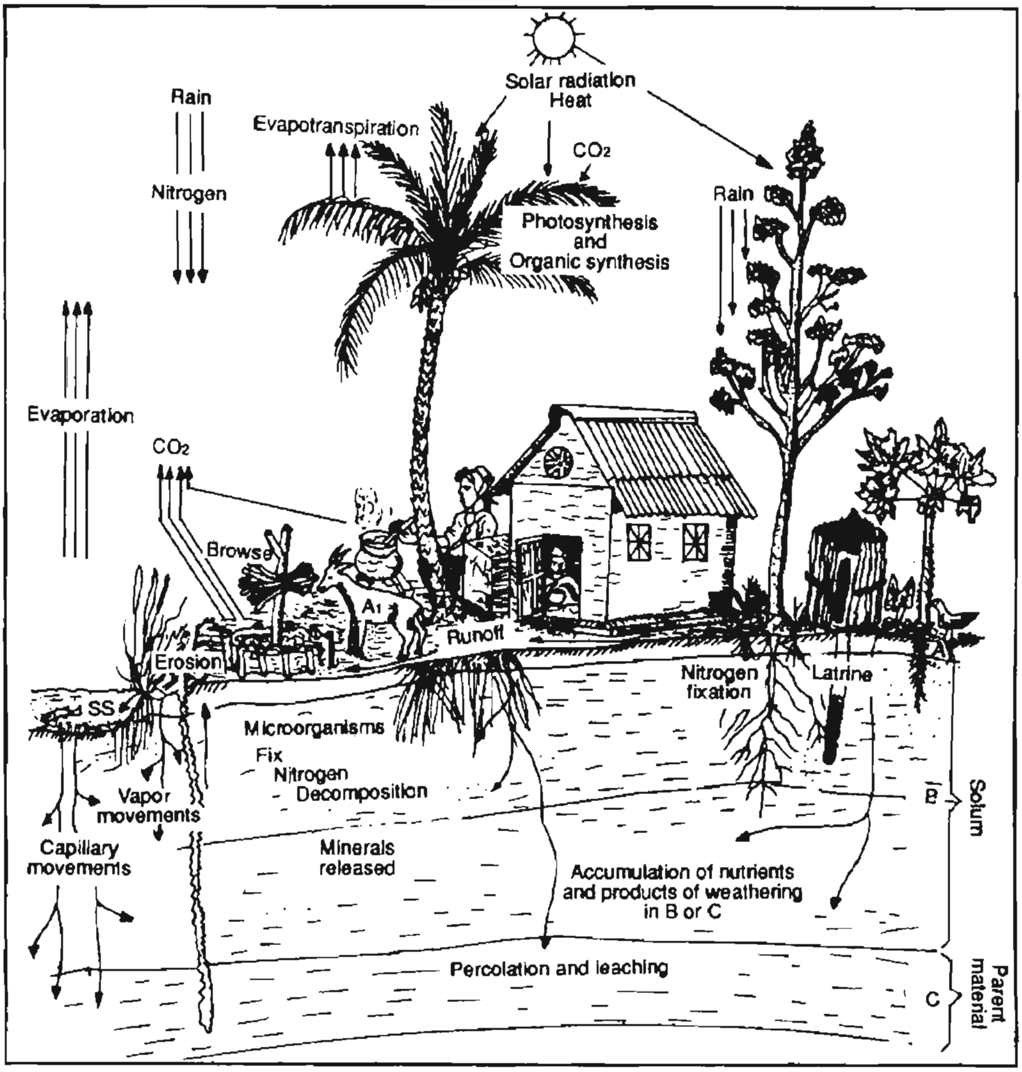


Figure 5. Recycling of energy and materials in a typical house garden.

environmental degradation. Of course, the system may continue to be maintained where a considerable amount of capital and materials are brought in from outside to stabilize the system.

It is, therefore, essential that in the development of sustainable agricultural production in Africa the existing systems, including the home garden, regulated ley farming, coconut/pasture agroforestry system, the Asian wet rice system, the commercial tree crop plantations, the banana/coffee production system, and the fadama or valley bottom production systems, are studied and understood. Based on such studies, the various underlying processes that made them sustainable can be identified and improved upon through research.

At the global level, the problem of sustainable development is that of how to share resources more equitably between the rich developed countries that have the economic and technological capabilities for tapping the world's resources and the developing countries that lack these. To arrive at an equitable manner of sharing these resources presents formidable socioeconomic problems. Whether we appreciate it or not, the ethical, moral, legal, political, ideological, and other cultural issues, including education, which we often ignore, remain at the core of the sustainability issues as the world becomes more of a global community. Africans need to get a better appreciation of the cultural problems and acculturation stress, created by what Mazrui (1986) calls the triple heritage, in finding a solution to some of the sustainability problems. But problems of political instability, resulting from colonialism and the clash of cultures, should not be used as an excuse for failure. Instead Africans should realize that the problem of sustainability in development is largely an African problem with global implications. It should not be left to the developed countries to solve. Since, as a result of self-interest and obvious political reasons, they may not go all the way to assist in finding a lasting solution, it is basically a political problem and African politicians, leaders, and scientists should recognize this. There is no doubt that developed countries have a lot to offer, but ways should be found to coax them to do so. Many of these issues are not on the research agenda of the IARCs, but at least they serve to emphasize the need for the CGIAR to give priority to finding ways for communicating more effectively with policymakers, ministers of agriculture, or, if possible, heads of state at least once a year. These are issues that African states need to understand at both the national and the international level in formulating policies and programs for sustainable development.

Resources for Sustainable Agriculture in Africa

Sustainable agricultural development requires a comprehensive or integrated approach in the policies, planning, conservation, management, processing, and utilization of natural resources. This means that sectoral development activities in agriculture (including fisheries and forestry, industrial and economic development) must be integrated in such a way as to minimize competition, maximize compatibility and sustainability, and reduce the adverse effects that they have on each other. Consequently, the agenda for sustainable agriculture in Africa must include the rational and efficient management of all the continent's natural resources in which agriculture is a vital component. The natural resources for agricultural production consist of (1) physical resources (climate, soils, and water), (2) biological resources (vegetation, animals, and mankind), (3) energy resources (human, solar, wind, water, geothermal, biomass, and mineral sources, including nuclear energy), and (4) human resources and institutions. Most of these resources are at least in part renewable. While the earth's mineral resources are usually regarded as nonrenewable, the soil, a key factor in agricultural production, is classified as renewable. This is because where it is not exposed to excessive runoff, erosion, and the elements, it can be managed in such a way that the rate of losses is balanced by the rate of soil formation resulting from the interaction of such factors as parent material, climate, and vegetation during a reasonable length of time. The extent to which these resources can be sustainably managed depends on their amount, quality, location, and availability, in addition to the strategies and technologies at our disposal.

Climate

This is made up of radiation, temperature, wind, and rainfall. Solar radiation consists of electromagnetic waves from the sun and their intensity, duration, quality, or composition. Location on earth significantly affects the temperature, wind systems, and rainfall. The incident solar radiation in Africa varies from a mean of about 330 cal/cm^2/day in the rain forest zone, near the coast and the equator, to over 580 cal/cm^2/day inland, near to the desert margins. The lower amount of solar radiation in the rain forest zone is the result of cloud cover. Solar radiation is the major source of energy for photosynthesis and several processes on earth. Where water is available, it enhances yields. Thus crop yields are higher in the savanna than in the humid areas, where sufficient moisture is available but it is often cloudy.

Temperature

This measures the quantity of heat in a place and is determined by the position of the sun. In January, when the sun is overhead south of the equator, mean temperatures range from about 21-26.5°C to above 32°C over much of southern Africa. In contrast in July, when the sun is overhead north of the equator, mean temperatures range from 15-25°C over most of western and central Africa to over 38°C over the Sahara desert. In January, the Atlas region of northern Africa has

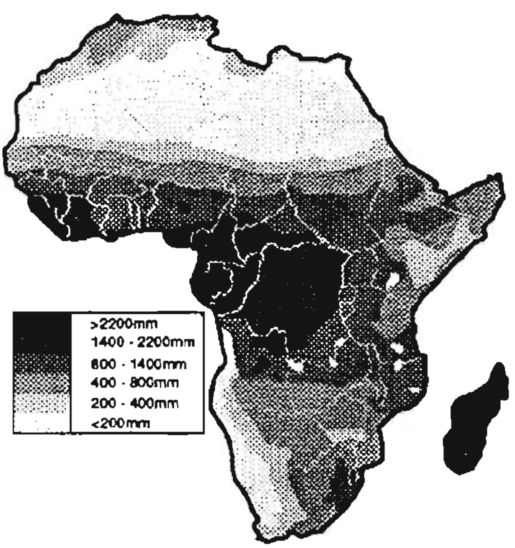


Figure 6. Annual rainfall in Africa.

a cool temperature of 10° C, while in July southern Africa has a mean of 15° C.

Wind

The wind system very much depends on the location of the sun, and a low pressure belt or zone moves north or south with the sun. Winds blowing to the low pressure center, when they pass over the sea or rise, bring rainfall. Thus high rainfall areas move north or south with the winds, and storms associated with them damage crops. Wind damage can be reduced somewhat with shelter belts or windbreaks. The force of the wind, on the contrary, can be harnessed to provide energy for work.

Relative Humidity and Rainfall

High relative humidities are usually encountered near the equator, where they are often above 80% throughout the year, especially in much of Zaire and the western coast of Africa. High relative humidities make the atmosphere stuffy and reduce work performance. Inland, and at higher latitudes, humidity varies with season and may be below 30% in drier months, especially in highland areas. Rainfall, which is determined by the apparent movement and position of the sun, as indicated by the intertropical convergence zone (ITCZ), varies from up to 4000 mm in some areas in the West Coast and Central Africa near the equator to less than 100 mm in semi-desert, arid, and desert areas of the Sahara and Kalahari deserts. Rainfall has great influence on vegetation and plant growth. Distribution of rainfall over the continent is shown in Figure 6.

Consequently, areas where the rainfall is high have high net annual primary productivities of 3000 to over 4000 g/m^2 (Figure 7). Where rainfall is below 500 mm per annum, it ranges from below 500 to 1000 g/m^2. It is in such areas that vegetation is sparse and irrigation is necessary for crop production.

As a result of interaction of the above climatic elements, especially rainfall and temperature, there are 6 broad climatic zones (as shown in Figure 8) consisting of (1) the humid zone, where annual rainfall is above 1500 mm with over 270 days length of growing period (LGP); (2) the moist subhumid zone, with mean annual rainfall of 1200-1500 mm and 180-270 days LGP, (3) the subhumid zone, with 600-1200 mm annual rainfall and 120-179 days LGP, (4) the semi-arid zone, with annual rainfall of 400-600 mm and 75-119 days LGP, (5) the arid zone, with mean annual rainfall of 100-400 mm and 1-74 days LGP; and (6) the desert zone, with less than 100 mm annual rainfall and no wet months for growing any crop (Table 4).

Water Resources

According to FAO (1986c), soil water is one of the most limiting factors in the develop-

Figure 7. Net annual primary productivity (g/m^2).

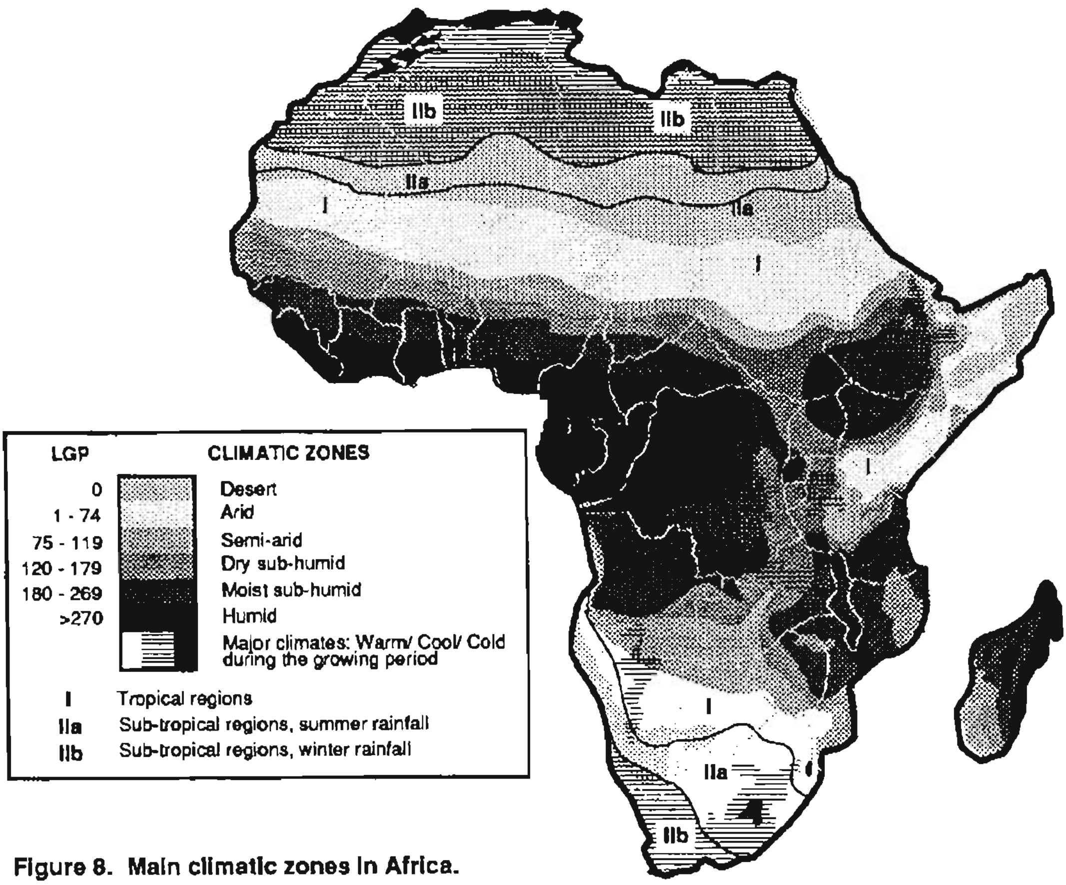


Figure 8. Main climatic zones in Africa.

ment of intensive land-use systems. The situation in Africa varies from that of some countries in the Sahel, with periodic drought, to others as in the east coast of Madagascar, with an annual rainfall of about 4000 mm and 2-3 months of floods. About half of the total surface water of the continent in lakes, rivers, marshlands, ponds, and streams is in the Congo basin. About 75% of the total is concentrated in the Chari-Logone, Congo, Niger, Nile, Ogooue, Sanga, Volta, and Zambezi basins. The mean annual runoff from rivers and lakes is estimated at 2.5 million m^3 of renewable water that potentially can be exploited for agriculture and other purposes. Africa has, on the average, excess precipitation over potential evaporation, but there are wide variations between the Sahelian countries and those in the more humid areas. For example, the percentage of potential evaporation covered by rainfall ranges from 151% at Yangambi in Zaire to 36% at Ouagadougou in Burkina Faso and 7% at Tamanrasset in Algeria. There is considerable year-to-year variation in rainfall in Africa, except in the more temperate areas. The duration and pattern of rainfall varies from a monomodal regime during 12 months to a bimodal regime of various durations to no rainfall at all. Depending on the duration, amount, and reliability of rainfall, crop cycles would be matched to the pattern of water availability. About a third of the continent is under crystalline metamorphic rocks, with very little water for wells. About 20% is underlain by calcareous rocks, with water in places for irrigation and other uses. Except for a few areas with silt and sandstones, the water table is too deep and wells very costly. The best aquifers are in alluvial fills of rivers, but river deltas along the coasts are too small and the sediments too fine grained to feed high yield wells. The alluvial valley amounts to only 100 million ha, and the alluvium tends to be shallow. The Sahara basin has very large groundwater basins, with similar recharge. The cost of extraction varies from high to low in a few places. Where it is used for irrigation, the water table is lowered. Thus Africa does not have large aquifers, with its shallow water table. Only in wetter areas, where the water table is high, are wells economical for irrigation. FAO studies of soil capability, length of growing season, extent of cold hazard, and water availability indicate that there is good rainfall in only 244 million ha (of the total potential arable land of 638 million ha), amounting to 38% of the potential arable land, while 10% has low rainfall, 45% constitutes problem areas, 7% is naturally flooded, and 1% is desert. About 18% of the area is suitable for irrigation. There are 60 million ha of irrigable land where rainfall ranges from 700-2000 mm annually, with surplus water for small-scale irrigation projects (FAO 1986c, d). However, only limited use has been made of water for irrigation and most of the irrigated areas, which amount to only 5% of the 18% potential of the arable land, are located in Egypt and the Sudan. In many of the areas with enough rain, health hazards limit the use of highly fertile valley bottoms and flood plains. While water is available for domestic, industrial, hydroelectrical, and other uses, data are not available to measure the demands and proportion satisfied; only about 6% of the potential hydroelectric power is currently being utilized.

Major Climatic Constraints to Sustainability

The major climatic constrains to sustainable food production in Africa include:

- Variability and frequent unreliability of rainfall, especially in semi-arid and arid areas (Figure 6).
- Unpredictable periods of drought, floods, and environmental stresses (low drought risk, 15%; moderate drought risk, 14%; and high to very high risk, 67%).
- High soil temperatures that adversely affect crops.
- Cloudiness in humid areas, reducing photosynthetic efficiency.
- Wind and storm damage to crops and erosion of soils.
- Deficiency in rainfall on over 54% of the land.
- High temperatures and humidity, favorable to pests and disease organisms.
- Problem of desertification in the Sudano-Sahelian zone, where rainfall deviation from normal exceeds 30%.
- Too-dry areas—47%.

Vegetation

Vegetation zones reflect the prevailing climatic and rainfall regimes as follows:

Climatic Zone (Rainfall, mm)	*Vegetation*
Humid zone (> 1500 mm)	Tropical rain forest, with high species diversity.
Moist subhumid (1200-1500 mm)	Evergreen forest, woodland, and derived savanna.
Dry subhumid (600-1200 mm)	*Parkia-Butyrospermum*—Khaya woodland, tree and shrub grassland, with *Andropogon* grasses; *Brachystegia-Julbertnadia* woodland (miombo), with shrub/perennial grass grassland in central/southern Africa.
Semi-arid (400-600 mm)	*Combretum* tree/shrub grassland with perennial grasses dominant; *Acacia-Commiphora* wood land in East Africa.
Arid (100-400 mm)	Sparse scrub and some perennial grasses present. *Acacia-Commiphora* woodland in East Africa.
Desert (<100 mm)	Very occasional dwarf, thorny scrub with some perennial grasses.

The agricultural production system and commodities produced follow these vegetation zones such that in the (1) *humid tropics*: tree crops, yams, cassava, cocoyams, bananas/plantains are dominant, with forestry important; (2) *moist-subhumid tropics*: cereals (maize, some rice, and sorghum), root crops (cassava and yams), with wheat and coffee in East Africa; (3) *dry subhumid zone*: maize, sorghum, groundnut, cassava, cowpea, rice, tobacco, and some soybeans are raised, with some livestock; (4) *semi-arid zone*: sorghum/millet, groundnuts, cowpea, and some maize are grown and nomadic pastoralism practiced; (5) *arid zone*: there is nomadic pastoralism involving sheep, goats, and camels, with some cattle raised and millet/sorghum grown; and (6) *desert areas*: nomadic pastoralists and hunter/gatherers predominate (Table 4).

According to the World Resources Institute (1988), the total area of closed forest in Africa is 217 million ha, or 10% of the land area, while that of total closed and open wooded forest area is 869 million ha or 40% of the land area. The annual rate of deforestation in Africa during 1976-1980 averaged 0.56%, but in Côte d'Ivoire and Nigeria it was up to 5.2% annually. Wild life habitat loss ranged from 29% in Zambia to 89% in the Gambia, up to the year 1986. Since 1981 there has been a 30% decline in the elephant population in Africa, and a 95% decline in the black rhino population. The number of threatened species of plants that are globally rare range from where there is no data to 1 in Niger, 226 in Mauritius, and 1,144 in South Africa.

Vegetation Problems

Tolba (1986) identified the following problems associated with the vegetation cover interacting with climate, man, and other organisms:

- loss of vegetation cover and destruction of vegetation;
- deterioration of rangelands;
- degradation of rainfed crop lands;
- waterlogging and salinization of irrigated lands;
- growth and encroachment of mobile sand dunes; and
- declining availability of water supplies.

Related to these problems are the loss of genetic diversity in plants and animals, exposure of soil to wind and water erosion, extinction or decrease in wildlife, and loss of useful plants that grow wild and their products. The pressure on vegetation has been intensified by the explosion in human and livestock numbers, and by human activities, including increasing intensity of farming, clearing and burning, hunting, overgrazing, and various construction and development activities.

Soils

As a natural medium for plant growth, soils are very important in agriculture. Together with the vegetation and animals they support, the soils constitute land, a very important factor of production in addition to labor and capital. Much of the soils covering the 2844 million ha of land in Africa have been formed over ancient crystalline rocks of the pre-Cambrian age, in association with small areas of sedimentary rocks and others of volcanic origin. These have formed major soil groups, consisting of Aridisols (34.5%), Alfisols (22.4%), Oxisols (22.4%), Entisols (12.1%), Ultisols (4.8%), and Vertisols (1.6%) (Figure 9). Most of these soils are highly weathered and of low inherent fertility, except for younger soils of volcanic origin, those found in valley bottoms and floodplains, and the black

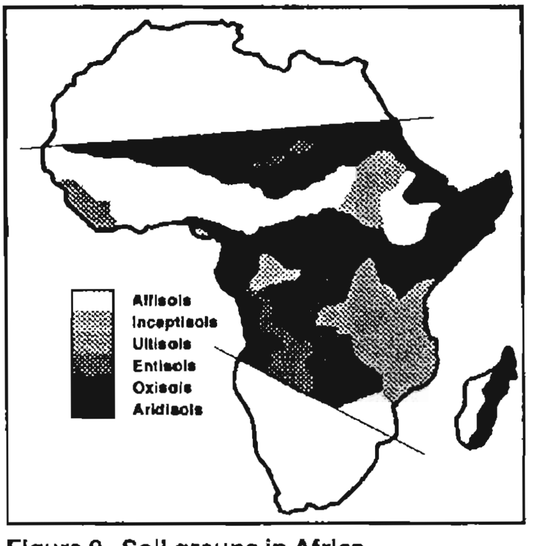


Figure 9. Soil groups in Africa

Table 4. **Extent of major climatic zones and land use in Africa.**

Climatic zone or region	Area in million ha and per-cent	LGP (days) and moisture availabi-lity	Rainfall (mm)	Land use and constraints
Desert	822.0 (29.1)	0 Deficit	< 100	Nomadic pastoralists and hunter gatherers, camels,sheep, goats. Too dry and hot for agriculture, except in oasis.
Arid	844.0 (17.1)	1-74 Deficit	100-400	Nomadic pastoralists, sheep, goats, camels, some cattle, millet and sorghum. High animal population, overgrazing, and deforestation causing soil degradation and desertification. Drought frequent.
Semi-arid	233.0 (8.1)	75-119 Deficit	400-600	Nomadic pastoralists and cultivators, millet, sorghum, cowpea, groundnut, some maize. Low potential for rainfed agriculture and very variable annual rains; nutrient shortage (N and P). Low night temperatures in dry season limit disease but constrain winter season cropping.
Dry subhumid	314.0 (11.0)	120-179 Adequate	600-1200	Zone of arable crop production-maize, sorghum, groundnut, cassava, cowpea, rice, tobacco, soybean, some animals. (cattle, sheep and goats). Declining yields and land degradation with fuelwood deficit or acute scarcity.
Moist subhumid	584.0 (20.4)	180-270	1200-1500	Transition zone with cereals (maize) and root crops (cassava, yam), banana, pineapple, sugar cane. Wheat, coffee in East African high-lands. Severe tse-tse fly infestation, which limits exploitation of livestock potential.
Humid	409.0 (14.3)	>270 Excess	>1500	Tree crop zone—oil palm, rubber, cocoa and food crops, yams cassava, banana, rice, pineapple + forest resources. Bimodal rainfall distribution may cause problems with cereal cultivation.

Source: FAO (1986a).

cotton soils. Except on high mountains and the 9% of the soils that are in areas with a cold climate, Africa can produce a wide range of crops and livestock, as indicated in Table 4.

Soil Related Constraints

Of all the factors available for agricultural production in Africa, soils appear to be the most important and limiting. African soils exhibit a range of physical, chemical, and nutritional deficiencies and other problems (Tables 5-7). Their management under increasing population pressure constitutes a major constraint to sustainability in agricultural production. The major constraints include:

- High degree of weathering, sandiness, deficiency in clay, high fragility, and erodibility.
- Low values of CEC and rapid rates of organic-matter decomposition.
- High levels of soil acidity and high tendencies for P-fixation.
- Highly subject to multiple nutrient deficiencies under increasing intensity of use and shortened periods of fallow.
- Proneness to leaching and high risk of erosion under prevailing tropical rainstorms.
- Low inherent fertility, with only 19% having no fertility limitations while 81% are problematic in one way or another.
- Serious salinity problems under irrigation, especially under poor water control or management.
- Large areas exhibit physical constraints, and 32.2% have various management problems (Table 6).
- Large areas exhibit chemical constraints, including 45% with low nutrient retention, 22.4% with low potassium supply, 22.3% with aluminium toxicity, 13.5% with phosphorus fixation, and so on (Table 7).

Table 5. Soil physical constraints to agricultural production in Africa.

Physical constraint	Area covered (million ha)	Percentage of total land area
Steep slopes	244.1	8.6
Sandy textures	866.4	30.5
Specific management problems	916.7	32.2

Source: FAO (1986b, e)

The area of African soils lost as a result of unchecked degradation is 83.5%. Overall, coarse textured soils amount to 19.7%, semidesert and desert soils 15.9%, soils with strong fertility limitations 14.6%, shallow soils mostly on steep slopes 13.2%, poorly drained soils 5.3%, heavy cracking clays 3.4%, and salt-affected soils 2.2%. It is obvious that African soils present formidable problems to sustainable agricultural development.

Energy Resources

Most of the energy in Africa for industrial use and transportation, according to the World Resources Institute (1988), comes from oil. The other major energy source is fuelwood. Africa has about 30,600 petajoules of oil, estimated to last 29.5 years at the 1986 production rate, as compared with 214,000 petajoules for North America. Resources of other sources of energy and number of years they are estimated to last are: natural gas 221,400 petajoules for over 100 years (compared with 311,000 for North America for 15.5 years); coal, 1.84 million petajoules for 362 years as compared to 5.6 million for 313 years, for North America. The African hydropower potential is 13,938 petajoules, of which only 674 petajoules (5%) is installed; North America has a potential of 14,695 petajoules, of which 6582 petajoules (45%) is installed. African production and consumption of commercial energy in 1986 amounted to 17,160 and 8102 petajoules, respectively. This consisted of 10,501 and 3421 petajoules of oil, 1792 and 1193

Table 6. Areas of land (in millions of ha) and percentage of area exhibiting different kinds of physical constraints in tropical Africa.

Region	Total land area	Steep slopes	Sandy texture problems	Specific management
Sudano-Sahelian Africa	828.2	50.9 (6.0)[1]	295.1 (34.9)	370.2 (43.7)
Humid and subhumid West Africa	206.6	15.3 (7.3)	57.5 (27.4)	63.0 (30.0)
Humid Central Africa	398.8	11.9 (2.9)	118.1 (29.6)	35.7 (8.8)
Subhumid and mountainous East Africa	251.0	54.6 (20.7)	19.1 (7.2)	52.2 (19.8)
Subhumid and semi-arid southern Africa	559.2	49.1 (8.7)	271.4 (48.2)	51.1 (9.1)
Total	2844.0	244.1 (8.6)	866.4 (30.5)	916.7 (32.2)

Source: FAO (1986b).

1. Figures in parentheses are percentages.

Table 7. Chemical constraints to agricultural production in Africa.

Chemical constraint	Land area affected (in million ha)	Percent of total land area
Low nutrient retention	1295.5	45.6
Aluminium toxicity hazard	635.0	22.3
Phosphorus fixation	382.5	13.5
Low potassium supply	637.0	22.4
Soluble salts	75.6	2.7
Excess of sodium	31.0	1.1
Excess of calcium carbonate	184.6	6.5
Sulfate acidity	3.8	0.1

Source: FAO (1986b).

petajoules of natural gas, 4149 and 2772 petajoules of coal, 674 and 42 petajoules of nuclear power production and consumption, respectively. The continent's commercial energy production amounted to 22% and 5% of those of North America and the world, respectively, and its consumption amounted to 9.5 and 2.5%, respectively. If Africa is to more equitably produce and consume commercial energy in competition with other regions of the world, its share of world production and consumption should be at least about 11%, which is the percentage of world population in Africa.

The proportion of the total energy supply in Africa from fuelwood amounts to about 80%, and it is estimated to range from 74% in the Sudan to 96% in Burkina Faso.

Energy source for agriculture in Africa is mainly from humans since most operations are performed manually. Manual labor accounted for 81% of farm power used in crop production, as compared to 16% for animal draft and 3% from machines in 1980 (Grigg 1985, Table 8).

Table 8. Percentage share of different power sources in the total power input for crop production in 1987.

Region or income level	Labor	Draft	Machines
Africa	81	16	3
Far East	64	34	2
Latin America	56	25	19
Near East	63	25	12
All low income	63	35	2

Source: Kinsey and Ahmed (1983), p. 227, and Grigg (1985), p. 161.

Sustainable agriculture production at reasonably high levels of productivity cannot be achieved in sub-Saharan Africa unless a substantial proportion of the human energy used in all phases of production and postharvest operations is replaced by alternative sources of energy. Similarly, considerable amounts of domestic energy, which currently comes from fuelwood, and commercial energy should be obtained from more diverse sources and African countries need to develop capabilities to make this possible.

Energy Constraints to Agricultural Production

One of the major constraints in agricultural production in Africa, especially sub-Saharan Africa, is the widespread use of manual labor and drudgery in agriculture. There is limited use of animal power, because of parasitic diseases of livestock in many areas and the high cost of mechanization. Associated with these is the acute labor shortage at peak periods of clearing and planting, weeding and harvesting. Debilitating endemic parasitic diseases sometimes render human energy unreliable and ineffective, especially during seasonal peaks of operations on the farm. As a result, timely operations are often not easily accomplished.

Fuelwood in Africa and other developing countries is used for (1) cooking, (2) water heating, (3) preserving food, (4) lighting and heating, (5) drying produce, and (6) social and ritual purposes. As fuelwood supplies become scarce, it creates serious problems for women who are already burdened with the following responsibilities:

- home production roles, including time spent in food processing and preparation;
- child care and care of members of the household, who are often ill, including self;
- fuelwood collection and gathering various things from the wild;
- household income-generating activities, such as those involving self-employment in crafts and trading or in services, petty skilled work on construction sites, and carrying of materials for the well-to-do;
- social activities, such as burial ceremonies (Figure 10).

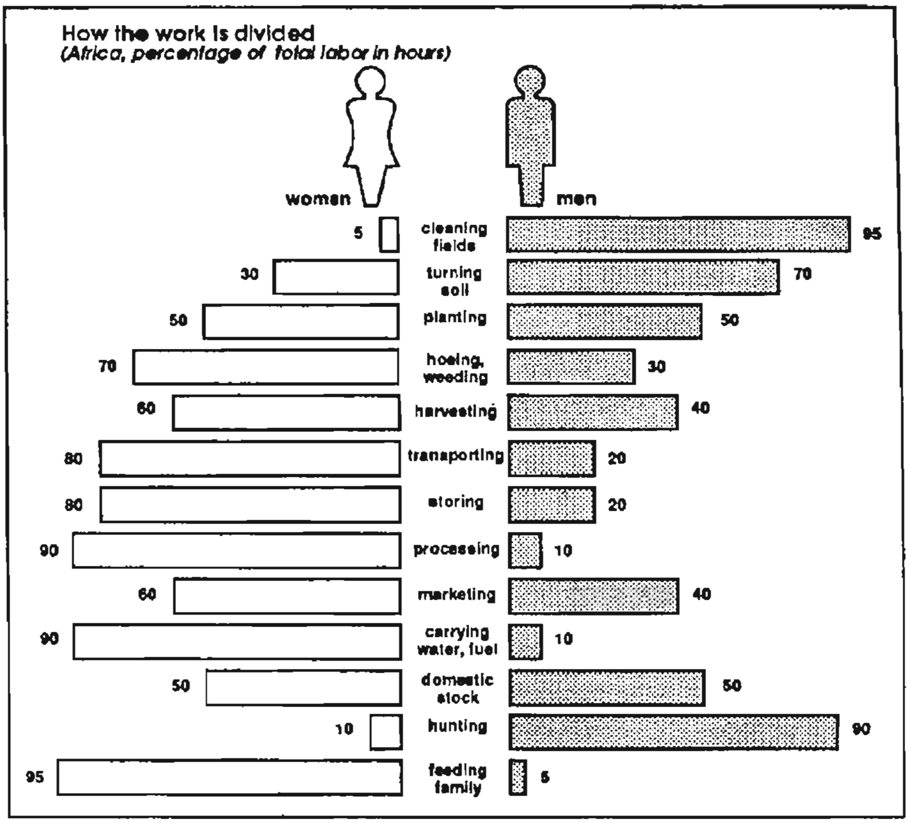


Figure 10. Division of labor between men and women (after Clarke 1987).

For more detailed information on the multiple roles of women in agricultural production, health care, and other activities refer to FAO (1982), Hoskins (1983), Cecelski (1987), Clarke (1987), and Leslie et al. (1988). The problems faced by women arise from the change in the time they have to devote to several activities in the traditional division of labor between the sexes in rural communities. Details about this, in terms of symptoms and associated work schedules, are shown below, based on Cecelski (1987):

Symptoms or effects of wood scarcity	*Increased work for:*
• Use of bushes, twigs, and roots as fuel	Women, children (gathering, preparing)
• Use of residues, fuels for cooking	Women, children (gathering, preparing)
• Walking long distances to collect fuel	Women
• Cutting living trees	Women, men
• Use of carts/animals to collect fuel	Men
• Purchasing fuel	Women or men (depending on who provides cash)

Time spent by women in fuel collection in different regions of the developing world is shown in Table 9. As more time is spent in collecting fuelwood, women and children are especially pressed for time required to accomplish other necessary tasks. Consequently, apart from energy loss and drudgery, they suffer stresses of various kinds. Fuelwood scarcity often also adversely affects nutritional status and health as it results in the following:

- less cooking;
- more eating of raw or undercooked foods;
- more eating of reheated or stale foods;
- less eating of fuel-intensive foods of higher biological or nutritional value (beans, grains);
- more cooking with smoky fuels;
- less space heating; and
- less washing with hot water (Cecelski, 1987).

Less cooking of meats containing eggs or reproductive structures of intestinal parasites or pathogens also adversely affects health.

Human Resources

Sustainable agricultural development depends a lot on the number of active, healthy, well-fed, educated, and well-trained individuals, who are adequately provided with the basic needs for food, water, sanitation, clothing, and shelter. In addition to raising the level of general education among the populace, there should be

Table 9. Number of hours spent by women in fuel collection and other activities.

Country	Agricultural work[1]	Non-agricultural work[2]	Fuel collection and cooking	Other[3]	Total hours worked
Indonesia					
Irrigated village	2.9	0.2	1.5	6.9	11.5
Upland village	3.1	0.5	2.4	6.0	12.0
India					
Average of five villages	3.9	4.0	4.8	0.9	13.6
Ghana					
Savannah village	1.3	2.7	5.0	5.0	14.0
Fishing village	2.0	6.3	3.6	2.1	14.0
Forest village	3.8	0.3	4.1	5.8	14.0
Mozambique					
Average of four villages	3.1	0.1	1.8	9.0	14.0
Peru					
Coastal desert	1.4	2.0	2.2	5.6	11.2
Sierra	4.0	1.0	3.8	2.4	11.2
High sierra	4.0	2.0	2.9	2.8	11.7

Source: Tinker (1982).
1. Family subsistence, wage employment, and livestock raising.
2. Crafts, food processing, and trade.
3. Clearing, child care, social, community and religious activities; for Ghana, travel time also included.

adequate numbers of technically qualified and experienced staff in research, extension, and agribusiness to ensure not only the staffing of the necessary institutions, but their sustainability. In Africa, there are high levels of illiteracy (over 70%) among farmers and poverty is pervasive. Overall, there is a deficiency in the human condition, not only with respect to poverty and malnutrition, but also because of the prevalence of many endemic debilitating parasitic diseases, including malaria, schistosomiasis, trypanosomiasis, onchocerciasis (river blindness), filariasis, and intestinal parasites in some areas. Areas affected by some of these parasitic diseases are shown in Figure 11.

Details on the problem of hunger in Africa have recently been reviewed by Ohse (1988) who, in addition to diseases, pointed out inadequacies in food production, traditional production systems, the peculiar problems of women farmers, ecological problems, weaknesses in transportation and communication, political instability, and deficiencies in policies. A comparative review of the basic human needs in relation to public health and nutrition in developing countries by Kaneko and Nidaira (1988) identified African countries as lagging behind in the levels of basic needs, especially with respect to health, nutrition, and economic development. Kamarck (1988) also reviewed the human condition in Africa and noted that 29 of 34 countries among the world's poorest are in Africa. He observed that since 1960 the average standard of living has fallen, while output has grown slowly, stagnated, or even dropped, and the rate of population growth has accelerated. While twenty years ago African exports accounted for 17% of the world's total, now they amount to only 10%. Table 10 shows that, with the exception of tea, Africa's contribution to the world's export crops has declined.

Africa, according to FAO (1986e), had an estimated population of 572 million in 1986, but the World Resources Institute (1988) reported the population is now above 626 million. This is projected to rise to 872 million by the year 2000; average annual growth rate is about 3.2%, the highest in the world. Where population is growing very fast and agricultural and industrial productivity remain low, there is usually malnutrition and poverty. This does not make for sustainability. Various indicators of the human condition, which attest to these, are presented in Annex 1. The overall institutional deficiencies and associated socioeconomic problems affecting sustainability in agricultural production are discussed next.

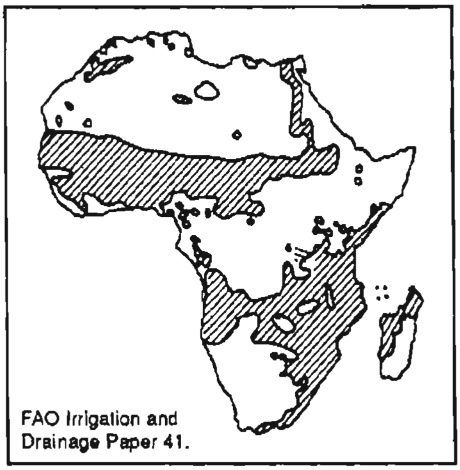
Table 10. Africa's share of the world's major agricultural exports.

Commodity	Period 1961-1963	1982-1984
Cocoa	63.6	40.5
Coffee	25.0	21.9
Tea	8.1	19.4
Cotton (lint)	18.6	15.3
Tobacco	11.9	8.7
Rubber	6.5	4.5
Sugar	5.0	4.8
Vegetable oilseeds and products (oil equivalent)	24.1	2.7

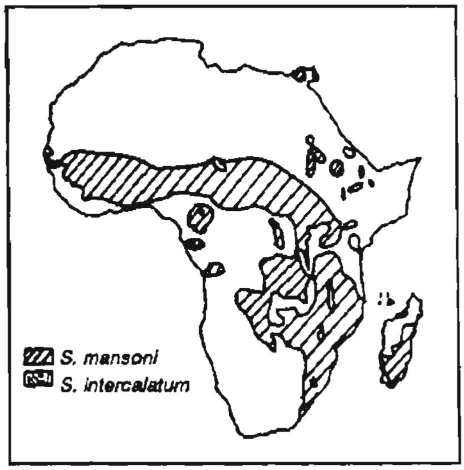
Source: FAO (1986a).

Institutional Issues

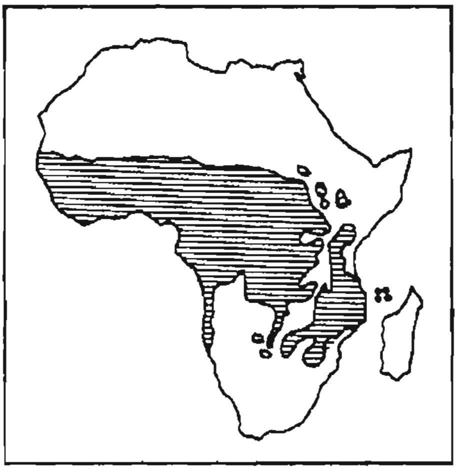
Ruttan (1977) observed that the level of productivity achieved in the developed countries is not yet within reach of most developing countries. This is because the developing countries have not yet made adequate investments on the physical and institutional infrastructure necessary for realizing the new productivity potential opened by advances in technology, which can be generated in relation to their specific resource endowments and level of institutional development. The institutional elements that interact in the development of technology and their adoption by farmers include: (1) research and extension; (2) education and training; (3) land (land, labor, and capital); (4) agricultural institutions for credit, cooperatives, marketing and pricing



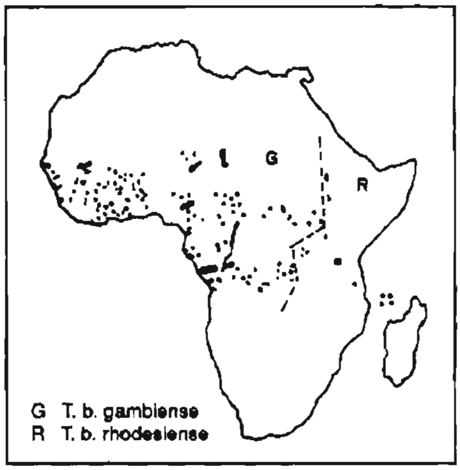
Distribution of *S. haematobium*



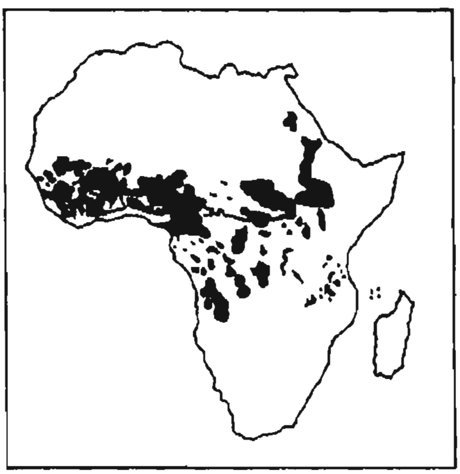
Distribution of *S. mansoni* and *S. intercalatum*



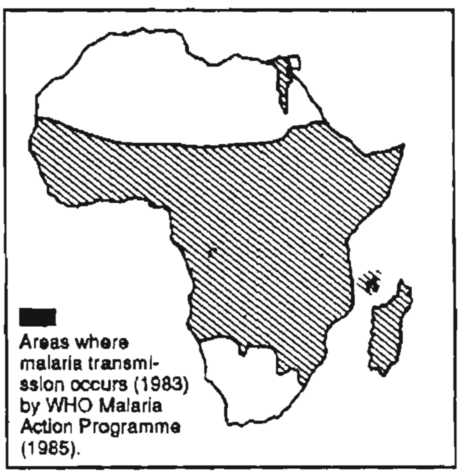
Tsetse fly belt.



African human trypanosomiasis: distribution of foci



Geographical distrbution of onchocerciasis.



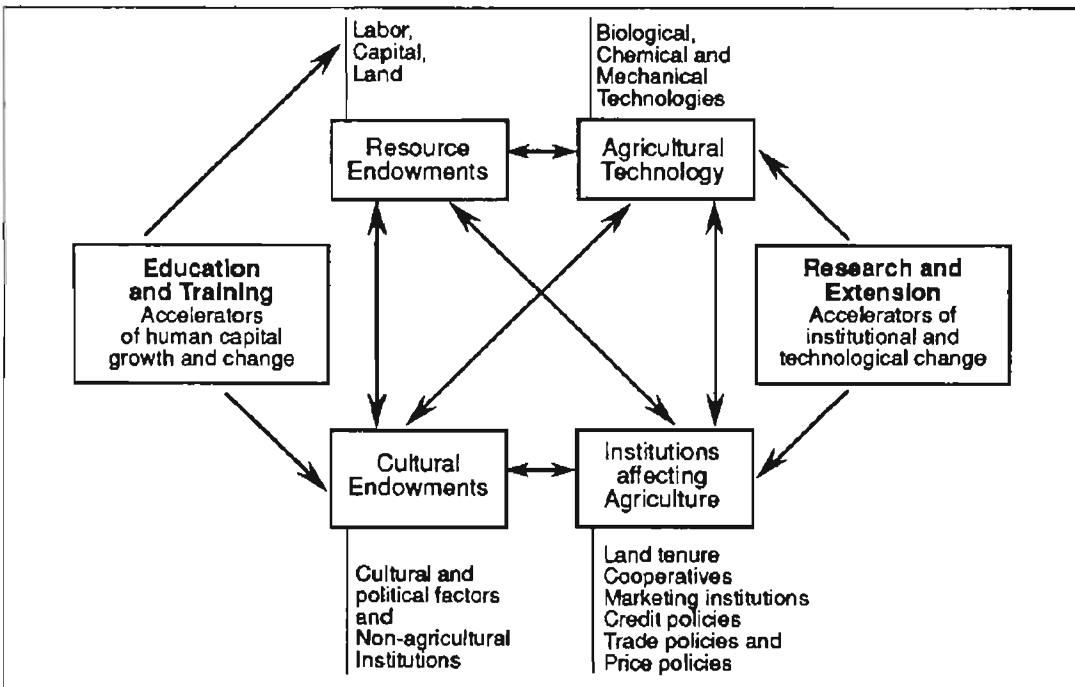
Malarious areas in Africa.

Figure 11. Prevalence of endemic parasitic diseases in tropical Africa (Kaneko and Nidaira 1988).

policies, and land tenure; and (5) nonagricultural institutions, in addition to related cultural and political elements (Figure 12).

The most important institutions include (1) government and administrative institutions, (2) research, extension, education, and training institutions. The importance of government and/or administration is due to the fact that it (1) provides the ideological umbrella under which priorities and development strategies are determined; (2) formulates policies for land tenure and agricultural institutions; (3) determines the administrative structure for the coordination of activities among government organizations and agencies; (4) ensures commitment to such development activities and institutions responsible for research and extension, which interact with other sectors; (5) plans and provides for infrastructural development; (6) allocates capital for various institutions and services; (7) determines the legal and legislative provisions under which various things are done; and (8) handles foreign policy and relationships with other countries (Stevens and Jabara, 1988).

The political situations in African countries do not engender sustainability. Factors that hinder sustainability in agricultural and economic development include (1) the endemic political instability of most African countries since independence; (2) their heavy debt burdens and the associated economic squeeze; and (3) the high proportion of the government budget being spent on the military. At least 21 African countries spend more than 10% of their budgets and at least 19 of them spend 5% or more of their GDP on the military (Table 11). Between 1975 and 1979, at the 1980 price/exchange rates, annual military expenditure peaked at about US$9 billion, more than 50 times the annual budget of the CGIAR. Yet many of these countries cannot afford to spend up to 1% of their GDP on agricultural research. Many of these countries are also too poor and too small to fund adequately and support effectively the development of a full range of institutions required for rapid agricultural development.



Source: Modified from Hayami and Ruttan (1985) and Stevens and Jabara (1988).

Figure 12. Relations between accelerators of social learning and elements of the Hayami-Ruttan Model of Induced Innovation.

As many as 37 African countries have populations of 10 million or less (Table 12). Other socioeconomic constraints to the development of sustainable agricultural production systems include the decreasing world market prices of major commodities, on one or two of which most of these countries depend for foreign exchange since about two decades ago (FAO 1986a), and the lack of environmental concern and of priority for measures to minimize environmental degradation, until the recent concern about the dumping of toxic wastes in some countries. It is not surprising, then, that many of these countries are still unable to execute the Lagos Plan of Action or the United Nations Special Plan for Africa, to which they are officially committed. Both of these plans give priority to agricultural development and food production.

Table 11. Military expenditure of African countries as a proportion of their government expenditure (1983) and GDP (1985).

Category and share (%)	Number of countries
Proportion of central government expenditure in 1983	
0-10	19
10-20	13
20-30	6
>30	2
Number of countries with data available	42
Proportion (%) of GDP in 1985	
0-2.5	5
2.5-5.0	3
5.0-7.5	5
7.5-10.0	8
>10	6
Number of countries with data available	27

Source: Kidron and Segal (1987).

Table 12. Population size and number of countries in Africa within a given population range.

Range (millions)	No. of countries
Over 500	0
100-500	0
50-100	1
25-50	4*
10-25	10
1-10	27
Under 1	10

Source: Grigg (1985)

* Excludes South Africa.

Educational and Training Institutions

Sustainable agricultural development as a component of overall sustainable economic development requires good educational and training facilities not only for imparting knowledge in all disciplines, but also for the acquisition of skills necessary for research and development in a scientific culture. Education has been regarded as an investment in human capital, but in Africa, many countries are not able to provide good educational services, and the deficiencies encountered include:

- inadequate funding and lack of good facilities for science education,
- lack of balance between theory and practice,
- more people trained in the arts and humanities than in the sciences,
- lack of vocational education facilities and adult training programs for many farmers who are illiterate,
- method of teaching and curricula not adapted to current needs, and
- lack of textbooks, and deficiencies in visual aids for teaching.

African Agricultural Research and Extension Institutions

In sub-Saharan Africa, research is conducted in national, regional, and international institutions. Concern about the African food crisis and the failure of research to show any impact on agricultural productivity has stimulated several papers on African agricultural research, including ISNAR (1984), Bennell (1986), World Bank (1987a, b), ISNAR/SPAAR (1987), Hayward (1987), Okigbo (1988a,b), Eicher (1988, 1989). All of these studies conclude that national agricultural research systems are weak and bedevilled by the following problems:

- Despite a growth in Africa of over 256% in research expenditure (Table 13) from 1959 to 1980, and a phenomenal growth of 300% or more in the number of research workers in many countries over 1962-1983 (Table 14), no significant impact has been achieved in agricultural productivity (Table 12),
- lack of adequate funding, facilities, and equipment;
- low quality of staff, with less than 0.5% having Ph.D. degrees, and limited experience;
- deficiencies in management and coordination of research;
- high rates of attrition;
- universities not effectively linked with NARS;
- poor linkage of research, extension, and the farmer;
- ill-defined priorities;
- many NARS still depend on expatriates even 20 years after independence;
- lack of incentives and promotional opportunities based on excellence and productivity on the job ; and
- considerable amount of human and financial resources spread thinly over many disciplines and substations in small isolated groups, which suffer intellectual isolation.

Many NARS lack the capability for taking advantage of technologies being developed at IARCs. Since the end of the colonial era, regional research institutes have broken down. There is need for upgrading, consolidation, reorganization, sustained funding, and provision of incentives if NARS are to contribute to sustainability in agricultural development.

Deficiencies also exist in extension and communication services. Hayward (1987) reported that in Africa from 1959 to 1980, more money was spent on extension than on agricultural research. The extension services often suffer from lack of logistical support, low contact hours with farmers due to high number of farmers per extension worker, a lot of time and effort devoted to input distribution, and the more experienced extension workers working more from the office than in the field.

Table 13. Global agricultural research expenditure (in thousands of US$, 1980).

Region	1959	1970	1980	Percent changes 1959-80
Western Europe	274,984	918,634	1,489,588	+442
Eastern Europe and the USSR	568,284	1,282,212	1,492,783	+163
North America and Oceania	760,466	1,485,043	1,722,390	+124
Latin America	79,556	216,018	462,631	+482
Africa	119,149	251,572	424,757	+256
Asia	261,114	1,205,116	1,797,894	+589
World	2,063,553	5,358,595	7,390,043	+258

Source: World Resources Institute (1988), which cites several other sources for this information.

Table 14. Full-time agricultural researchers employed by government institutions in sub-Saharan Africa, 1962-1983[a].

	1962[b]	1971[b]	1983	% increase 1962 - 1983
West Africa				
Burkina Faso	6	10	125	1983
Benin	10	16	56	460
Chad	10	26	20	100
The Gambia	5	5	23	360
Ghana	80	140	168	110
Côte d'Ivoire	60	110	202	142
Liberia	16	14	27	69
Mali	15	25	244	1526
Mauritania	4	7	9	125
Nigeria	170	300	986	480
Senegal	55	130	205	272
Central and Southern Africa				
Botswana	2	33	61	2950
Cameroon	15	72	153	920
Lesotho	2	7	18	800
Madagascar	40	70	75	87
Malawi	22	57	106	381
Mauritius	30	51	83	177
Swaziland	6	12	15	150
Zaire	25	66	111	344
Zambia	31	81	177	470
Zimbabwe	100	172	173	73
East Africa				
Burundi	13	24	7	-46
Ethiopia	12	52	159	1225
Kenya	40	210	609	1422
Rwanda	10	16	30	200
Sudan	50	128	272	444
Tanzania	60	100	341	468
Uganda	32	80	154	381

Source: Bennell (1986), Table 4; Bennell cites other sources for this information.

Notes:
a. Crops, livestock, and forestry researchers in nonuniversity institutions.
b. Figures for 1962 and 1971 are in "scientific man years".

This review is by no means exhaustive, but the weaknesses exhibited in research, administration, education, and training are also observed in all the institutions for credit, cooperatives, and so on. Related to extension is the fact that despite the explosion in information and informatics, there is poor communication among research workers, and among researchers, policymakers, and farmers. Scientists are isolated from the global scientific community.

Sustainability Perspective in Strategies for Increasing Food Production

The current concern about sustainability in agricultural production calls for the adoption of a sustainability perspective in the choice of strategies for increasing agricultural productivity through (1) expansion of area under cultivation; (2) increased production per unit of land and unit of input; (3) genetic improvement of crops and farm animals; (4) mechanization and appropriate technology; (5) integrated management of pests, weeds, and diseases; (6) improvements in, and broadening the range of, postharvest technologies; (7) better management and utilization of forest and range resources; (8) improved pasture management; (9) better management and utilization of aquatic resources; and (10) use of nonconventional food production methods, especially with regard to opportunities offered by advances in biotechnology. A sustainability perspective requires that in each of these areas

- greater priority be given to monitoring of environmental consequences on a short-term and long-term basis,
- care be exercised in technology choice for operations ranging from land clearing to harvesting and the postharvest phase,
- the scope of basic or strategic research be increased, and
- a more holistic and systems approach be adopted in research.

Expansion of Area Under Cultivation

The population explosion necessitates intensification of production, greater use of land-saving technologies, limiting expansion into marginal lands, and making provisions for increasing multiuse pressures on the land. The land now under cultivation per capita is not lower than in southeast Asia. Although FAO (1984) projected that up to 3 times the 1975 population of 380 million can be supported by using the entire cultivable land area, by the year 2000 up to 29 countries and 466 million people will be at risk because of low inputs (Table 15). Moreover, since only 28% of the potential land area is suitable for rainfed agriculture, the only choice for an expansion of the area under cultivation is by using more valley bottoms or hydromorphic areas that have a high productivity potential for expansion of irrigation by small-scale projects and

Table 15. Critical countries and affected populations in Africa.

Year	Input level	Population (millions)	Number of critical countries	Populations affected (millions)
1975	Low	380	22	128
	Intermediate		7	25.5
	High		2	10.4
2000	Low	780	29	466
	Intermediate		12	110
	High		4	11

Source: FAO (1984).

improved drainage at reasonable cost. Only by balancing the use of biological (nitrogen fixation and mycorrhizal phosphate nutrition) and artificial fertilizers can this be achieved. More fertilizers have to be used in African agriculture for food crops than the 14 kg per hectare being used mostly on food crops (as compared to 38 kg/ha for export and nonfood crops) (Table 16). It is expected that by the year 2000 expansion of area under cultivation would account for only 22% of yield increases, higher yields for 51%, and cropping intensity for 27% (FAO 1981). More reliable analysis of fertilizer use (especially of N and P) is needed, as a basis for determining the extent and the effectiveness of fertilizer use. Where most of the nitrogen is derived from biological nitrogen fixation and excess phosphatic fertilizers are not used, there is minimum danger for high levels of nitrogen and phosphorus pollution.

Increasing Cropping Intensity

This should receive high priority in efforts to save land for other uses. It can be best achieved through better management of diversity, and through temporal and spatial arrangement of cropping patterns. The IARCs need to do more work on simple rotations, monitored over longer periods of time, and development of better methods for studying both the above-ground and underground crop competitions so as to take advantage of such phenomena as allelopathy, wherever possible. Also needed here are studies of the physiology and ecology of crops under field conditions.

Genetic Improvement of Crops and Livestock

Genetic improvement of crops facilitates increased yields; development of varieties resistant to environmental stresses, pests, and diseases; adaptation of cultivars to

Table 16. Estimated fertilizer used per year during 1979-81, in terms of fertilizer nutrients.

Region of Africa	Total quantity of fertilizer used (100 m.t.)	Quantity of fertilizer used (kg/ha)	
		Export and nonfood crops	Food crops
Mediterranean and arid North Africa	1218 (57.1%)	92	71
Sudano-Sahelian Africa	117 (5.5%)	59	2
Humid and subhumid West Africa	251 (11.8%)	14	5
Humid Central Africa	47 (2.2%)	19	1
Subhumid and mountain East Africa	139 (6.5%)	35	4
Subhumid and semi-arid Southern Africa	361 (16.9%)	89	14
Total	2133	38	14

Source: FAO (1986a).

Table 17. **The economic and social impact of animal diseases in Africa.**

Mortality	Rinderpest, tick-borne diseases, trypanosomiasis.
Lowered Productivity	
(a) Infertility	Malnutrition, brucillosis
(b) Loss of weight	Malnutrition, distomatosis, gastro-intestinal parasites, ticks.
(c) Loss of draft power	Malnutrition, distomatosis, gastro-intestinal parasites, ticks.
Denial of Land Use	Trypanosomiasis.
Denial of Export Markets	Rinderpest, foot-and-mouth disease, contagious borne pleuropneumonia.
Impairment of Genetic Improvement Programs	Tick-borne diseases, streptothricosis, foot-and-mouth disease.

Source: Tropag Consultants Ltd. (1986) and Odhiambo (1988).

mechanization and different production systems; enhancement of quality; and development of cultivars that are more efficient in the utilization of resources or inputs and that meet the changing needs of consumers and producers. IARCs should assist NARS to gain access to some of the emerging potentialities of biotechnology. Genetic improvement also contributes to integrated pest management, and reduces losses from parasitic diseases of livestock (Table 17). There is still a lot of underutilized potential in the genetic improvement of indigenous African crops and the introduction of exotic germplasm.

Mechanization and Appropriate Technologies

In sub-Saharan Africa, the extent of land area mechanized ranges from as low as 1.4% in the humid Central African countries to as high as 36.3% in the mediterranean North African area (Table 18). Mechanization is vital in reducing drudgery, getting more young people into farming, achieving timeliness of operations, and addressing the shortage of labor at peak periods of demand. There is need for giving special attention to the needs of women, especially in the postharvest phase, and encouraging the training of crews of younger men and women for running private equipment hiring services, which can provide various services and engage in the fabrication and maintenance of simple equipment. More attention should be given to the environmental effects on land, air, and water. More efforts should be made to study alternative energy sources and the benefits derived, as opposed to the disadvantages in their use.

The following cogent conclusions and observations on mechanization in Africa from Pingali et al. (1987) should be given due consideration in programs aimed at increasing the replacement of human labor by machines and/or animals:

- The transition from the hand hoe to the animal-drawn plow is only profitable at higher intensities of farming.

- The substitution of mechanical tillage for hand tillage has a minimal effect on yields.

- It is not unusual for farmers to persist in the use of hand hoe in some intensively cultivated regions, and it has not been possible to use the tractor to accelerate significantly the evolution of farming systems to permanent cultivation.

Table 18. **Use of tractors in different regions of Africa in 1982 and growth rate in 1975-1982.**

Region of Africa	Available land area: Total cultivated area (1,000 ha)	Available land area: Percentage mechanized	Tractors: Total number and % share	Tractors: Annual growth rate (%), 1975-82	Available land per tractor (ha)
Mediterranean and arid North Africa	22362	36.3	162300 (56%)	4.56	138
Sudano-Sahelian Africa	30588	24	15981 (5.5%)	4.53	1914
Humid and subhumid	38011	1.8	17120 (5.9%)	3.40	2220
Subhumid and mountainous	23875	2.7	16328 (5.7%)	2.02	1402
Humid Central Africa	14716	1.4	5152 (1.8%)	5.00	2856
Subhumid and semi-arid	22547	13.5	71090 (24.6%)	1.46	317
Total	152099	8.8	287971	3.52	528

Source: FAO (1986a).

- In permanent cultivation systems, an opportunity sometimes exists for replacing draft animals with tractors. Whether this transition is cost-effective must be analyzed in each case on its own merit.

- The direct transition from the hand hoe to the tractor at the late bush fallow and early grass stages is not cost-effective.

- Two environments in which direct transition to tractors may be cost-effective are valley bottoms and flood plains where irrigated or flooded rice is cultivated, and the grassy savannas in the semi-arid zones.

- Historically, too much emphasis has been placed on a self-defeating effort to tie biological technology to mechanical technology.

- The profitability of animal-drawn or tractor-drawn equipment is constrained by the length of the growing season.

Forest and Range Management

There is a need to give more attention to integrated and alternative strategies of grassland management that enhance sustainability, through such practices as game ranching and improved range management, which maximize benefits in conservation, supply of meat, reduced environmental hazards, etc. (Table 19). This takes advantage of stratification and differential ecosystem use by livestock and wild animals (Figure 13). Special attention should be given to the management of fire and vegetation. More serious attention should be given to ensuring that there is no overgrazing, since some regions of Africa have already exceeded their carrying capacity (Table 20). The beneficial effects of germplasm conservation and diversity in

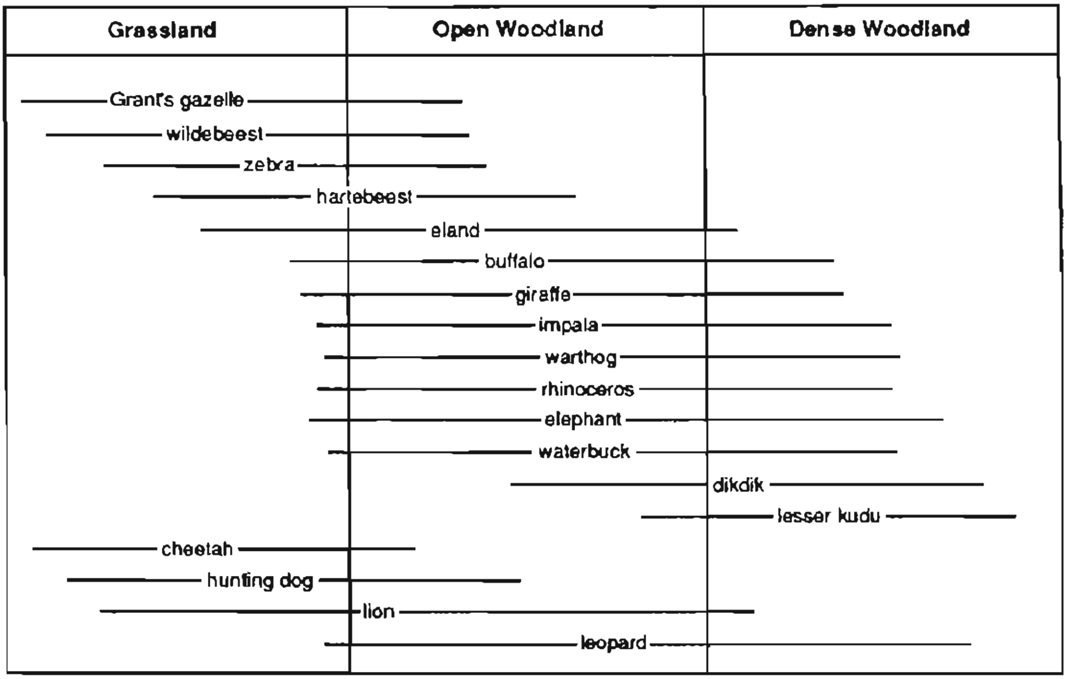


Figure 13. Habitat and food preferences of animals in the Tarangire Game Reserve (after Lind and Morrison 1974).

Table 19. Benefits of alternative strategies of grassland management.

	Potential benefits[1]									
Management strategies	Meat supply	Damage control	Animal export	Trophies & skins	Tourism	Econ. dev.	Conservation research	Research	Disease control	Employment
None[2]	(C)	C	(C)	(C)	I	I	I	I	C	I
Livestock ranching	N	C	I	I	I	N	N	I	C	N
Game preserves	N	C	C	N	C	C	C	C	I	C
National parks	N	C	C	N	C	C	N	C	I	C
Game ranching	C	C	C	C	N	N	N	C	C	N

Source: Knight (1976).

1. Allow traditional hunting, agriculture, and pastoralism to continue development in grassland areas.

2. C = Compatible; (C) = Compatible but for limited duration in grassland areas; N = Natural; I = Incompatible.

Table 20. Levels of grazing land in different regions of Africa in 1980.

Region	Suitable for grazing (million ha)	Not suitable for grazing (million ha)	Current stocking level (million ha)	Carrying capacity (million ha)	Million TLU under/over stocked
Mediterranean and arid North Africa (17.5%)*	105.0	495.0	19.5	17.6	+1.9
Sudano-Sahelian Africa (64.0%)*	530.0	298.0	52.0	44.0	+8.0
Humid and subhumid West Africa (73.0%)*	150.0	56.3	18.0	38.0	-20.0
Humid Central Africa (47.5%)*	190.5	210.0	5.0	95.0	-90.0
Subhumid and mountainous East Africa (78.0%)*	196.0	55.0	50.0	49.0	+1.0
Subhumid and semi-arid Southern Africa (81.5%)*	454.0	105.0	30.0	40.0	-10.0

Source: FAO (1986a, b).

* = Percentage of total land suitable for grazing

Note: If current trends continue, by the year 2010, carrying capacity of range lands will be greatly exceeded in North, Sudano-Sahelian, and East Africa.

the maintenance of ecological balance and a dynamic equilibrium should be used in enhancing the environment. Many underutilized species offer opportunities for domestication and have a multiplicity of uses in agroforestry. Intensification of land use usually involves deforestation and various land-use alternatives, including growing forest plantations, using agroforestry systems, or growing row crops. Deforestation per se and the various land-use systems after it are associated with varying degrees of environmental degradation (Figures 14, 15, 16). In land clearing and development, the choice of mechanical equipment that is appropriate and care in management of the soil often determine the extent of erosion and soil degradation that results. The main uses of forests include supply of wood, recreation, minor forest products, pool of germplasm and useful genetic information, potential species for domestication, stabilization of climate, soil protection, etc. Appropriate management strategies should be used to maximize these uses. Jacobs (1981), Dasmann et al. (1973), and IUCN (1975, 1980) provide useful guidelines for forest exploitation and conservation.

Better Management and Utilization of Aquatic Resources

Just as with forests, the improved management of aquatic resources contributes to our food resources, and it can feature in integrated watershed management and development.

The total fish production of African countries in 1979, according to FAO (1986c), amounted to 3.7 million t, of which 2.1 million t (56%) was from sea fisheries and 1.6 million t (44%) from inland fisheries. Fish protein

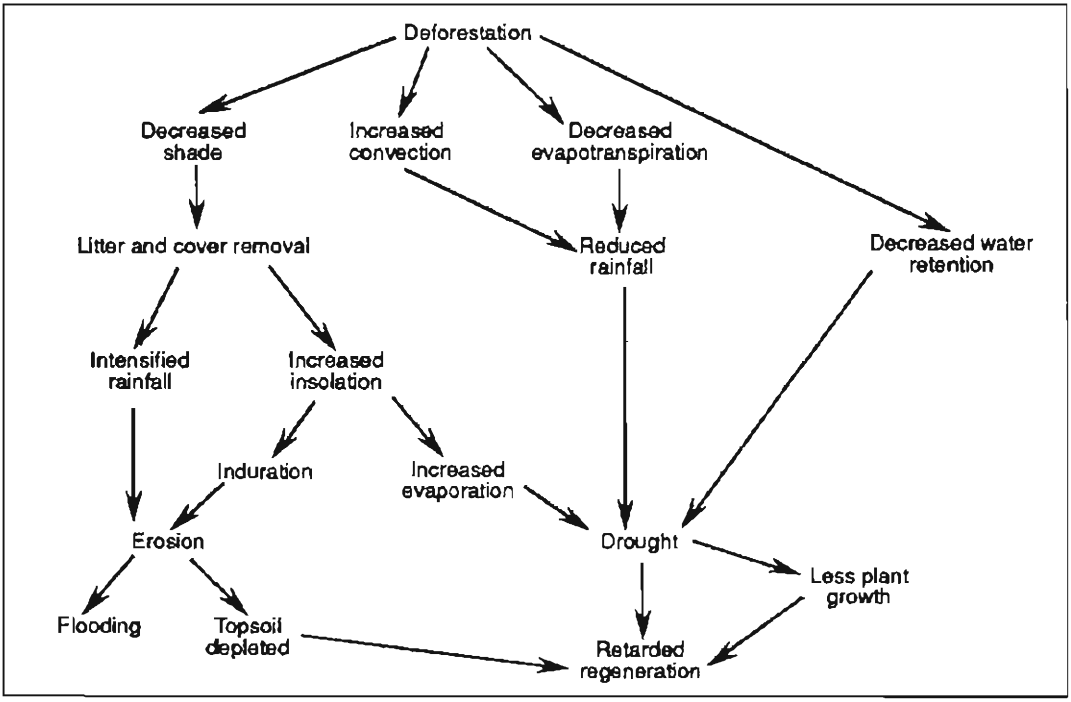


Figure 14. Diagram showing the consequences of deforestation for the environment of the area (Goodland and Irwin 1975).

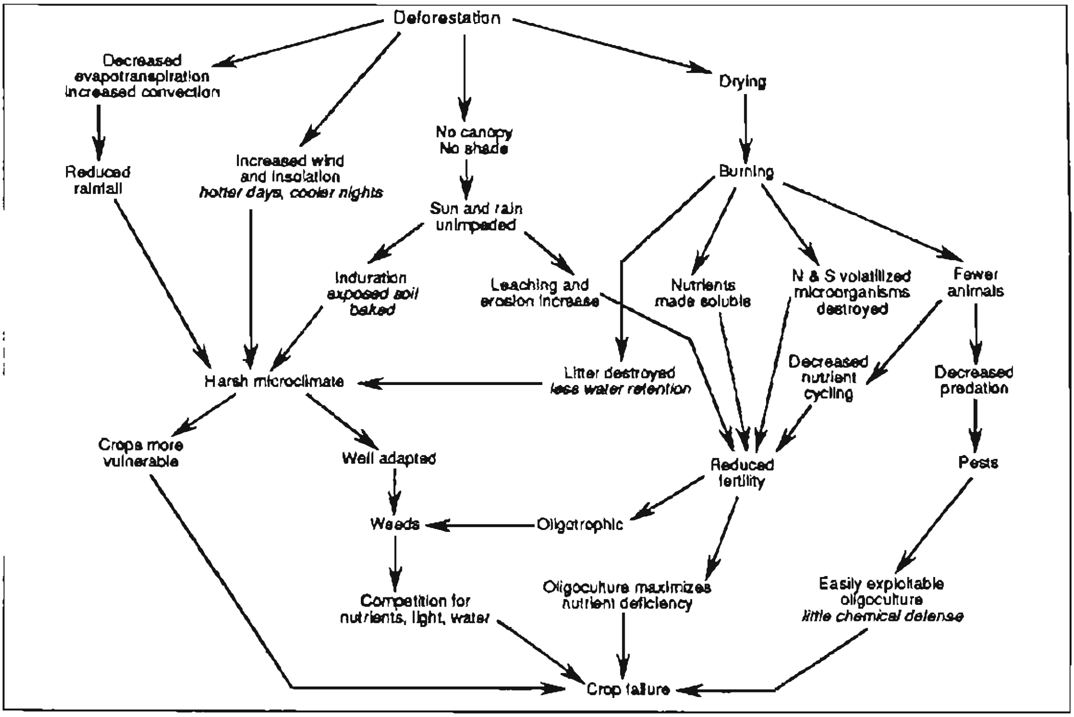


Figure 15. Relationship between deforestation and crop failure (Goodland and Irwin 1975).

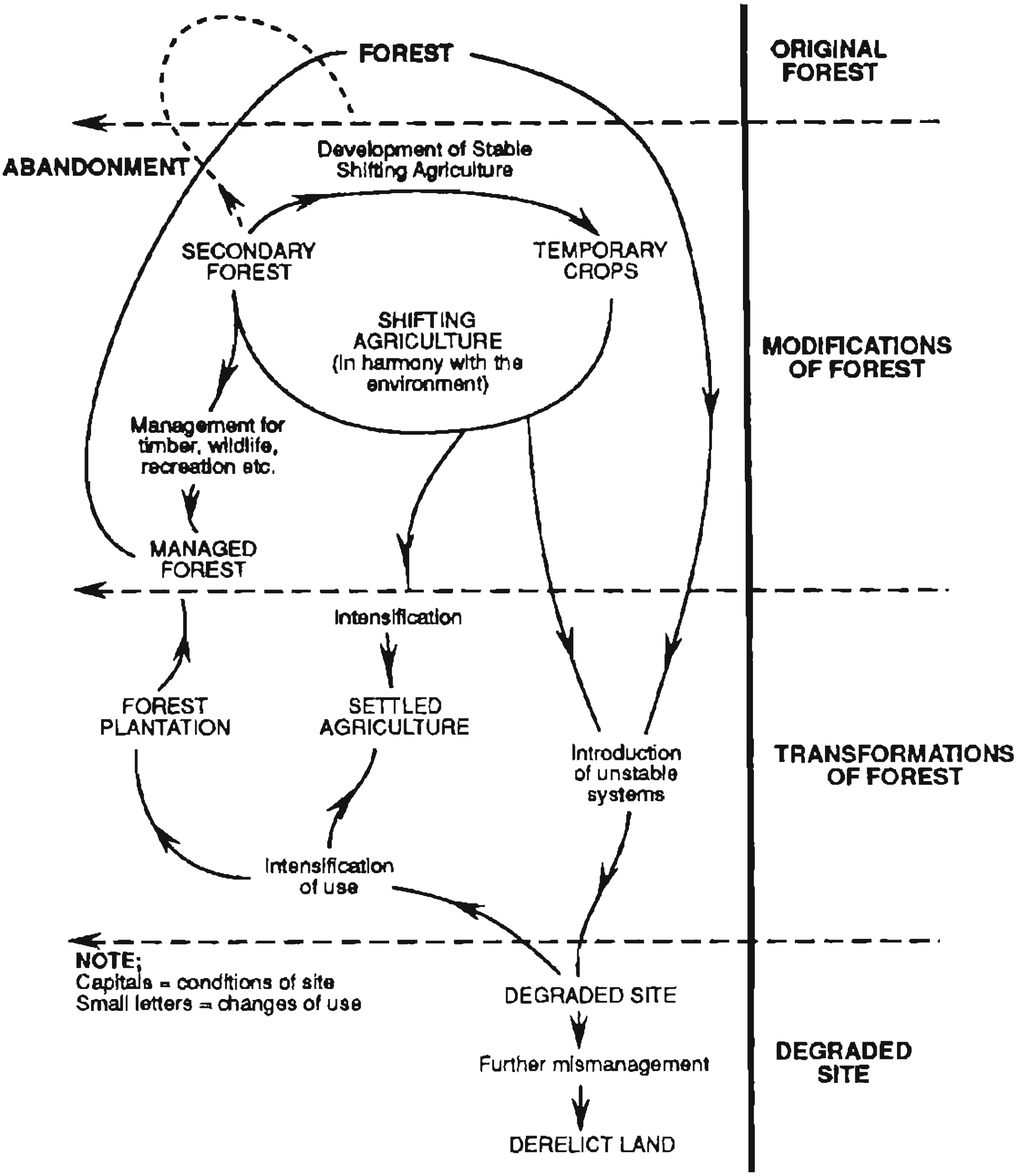


Figure 16. Relationship between shifting cultivation and other land uses in each of the four categories (Jacobs 1981).

accounted for more than 40% of animal protein in 10 African countries, and 20-40% in another 14 countries. With a potential sea fisheries catch of 8.8 million t, only 5.6 million t catch was recorded in 1979, of which African countries accounted for 2.1 million t. There is, therefore, a lot of opportunity for improvement. Considerable amounts of the employment opportunities in fisheries have not been exploited and, apart from low productivity, spoilage is estimated at up to 50%. The inland water fisheries, (water bodies) amount to over 150,000 km^2, in addition to 64,000 km^2 of brackish water.

The total inland water fisheries catch of 1.6 million t in 1979 amounted to 80-84% of the 1.9-2.0 million t potential. FAO (1986c) reports that there is room for some increased production from better management, new fishing methods, better access, and improved processing to minimize spoilage. With the exception of outboard motors, no really improved technology is being used in inland fisheries. Problems of development of inland fisheries include those of several competing water uses for irrigation, electropower generation, domestic use, waste disposal, etc. Considerable losses in fisheries also result from siltation, deforestation, and poor soil conservation within watershed areas.

The research and development of fisheries is mainly the responsibility of NARS. But since scientific production of fish (aquaculture) is still in its infancy and accounted for only 100,000 t of fish in 1975, as compared with 340,000 t from rivers and streams, this has a lot of potential as a component of integrated watershed development, in which land use is shared with crops and other animal enterprises. With the exception of the FAO Regional Aquaculture Center at Port Harcourt in Nigeria and a few national research institutes, no major well-equipped and staffed institute is involved in fisheries research that is consistently or adequately funded and equipped to an extent commensurate with the potential of fisheries' contribution to nutritional well-being and development.

Better management of aquatic resources relieves some pressures on the land and yields high quality food, with fish being increasingly preferred to meat. Many aquaculture products are acceptable in different societies, but there are problems of pollution by physical and chemical contaminants. Aquaculture organisms concentrate pollutants and produce waste several times their weight (Gabel, 1979). Monitoring of pollutants and prevention of diseases is very important in aquaculture. For a more detailed review of the problems of fisheries development in Africa, and the advantages and disadvantages of aquaculture, refer to FAO (1986b, c) and Gabel (1979).

Better Management and Improvement of Pastures

Improved nutrition is very important in animal production and the use of improved pasture management techniques, such as rotational grazing, use of improved legumes and grasses, better fire management, special agroforestry systems, etc., promises to contribute not only to increased production but also to improved environmental quality. There is need to use a greater range of indigenous and introduced species in pasture improvement, and to find ways of utilizing the higher productivity of the Guinea savanna in the fattening of livestock initially raised in the drier savanna areas, free of many parasitic diseases but low in pasture productivity.

Integrated Pest, Weed, and Disease Management for Crop and Livestock

This offers a lot of opportunities for combining compatible mechanical, biological, cultural, and chemical techniques in pest and disease management. It minimizes the adverse environmental effects of pesticides, but requires a wider scope of basic research on the biology and ecology of organisms, and an understanding of micro- and macroclimatic variables for several species of organisms and of other environmental factors. Monitoring of pesticide residues should be based on the understanding of the chemical pathways by which these chemicals get to man (Figure 17). Studies of pesticide residues should be conducted in strategic on-site and off-site locations that are likely to be affected. There is a need for a major center for integrated pest management studies on a wider range of crops in Africa. In this regard, IITA's Biological Control Program at Cotonou constitutes a good beginning, but there is a need to increase training opportunities for Africans. Experience shows that in this linkage with several institutions worldwide is necessary.

Postharvest Technology and Good Processing

These are very important in sustainability of production, since they minimize losses, can enhance quality, facilitate storage and dis-

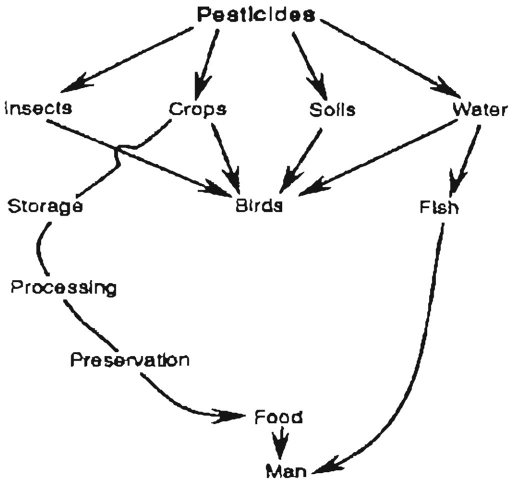


Figure 17. Pathways by which pesticide residues get to man (after Birch et al. 1977).

tribution, especially of bulky commodities (such as cassava) that are difficult to handle and transport, and increase demand for crops like cassava when they are available in more convenient forms for urban masses and the more affluent. More specifically, they provide opportunities for employment and income generation through value added (Figure 18). The IARCs need to increase the scope of postharvest research and give more attention to the problems of women and the monitoring of environmental hazards involved, on-site and off-site.

Nonconventional Foods

An aspect that has high potential is the use of biotechnology in dealing with various wastes and effluents from processing. It could, therefore, be linked with postharvest research.

The Problem of Planning and Design in the Development of Sustainable Agricultural Systems

It is obvious that development of sustainable livelihoods and agricultural production systems calls for a more holistic and integrated approach in all aspects of natural resources conservation, management, and utilization. This minimizes competition among agriculture, forestry, fisheries, industry, and other development activities. It also calls for more in-depth understanding of environmental variables, and for focusing the production of commodities at locations where they are best adapted and have economic and ecological advantages. The strategy needed involves planning based on stratification of environments at macro and micro levels, and then developing technologies and designing alternative management systems within each stratum. In most IARCs and NARS, experience so far shows that more time is devoted to data collection, analysis, and preparation of reports than to planning and designing experiments, technologies, and production systems to be tested on the basis of previous years' results. Sometimes, the following year's experiments and studies are started before the previous year's data have been fully analyzed and implications of the results studied.

Macrolevel Regional Stratification

This involves the development of agroecological management plans, based on ecological considerations with respect to rainfall regime, moisture availability, and related climatic factors, crop physiological data, broad soil characterization data, and crop dominance and preference criteria, in addition to relevant socioeconomic variables. Oram (1988) has reviewed in greater detail what this entails, the various disciplines involved, the progress to date in related research and studies by FAO and some IARCs, and made suggestions on future work. There is need for an exercise of this kind in delineating the humid and subhumid tropics of Africa into major benchmark areas for different commodities and cropping systems, as shown in Figure 19. Then, within each benchmark area, smaller areas can be delineated, on the basis of more microecological considerations and landscape characteristics, into areas where different production systems of interest are practiced. IITA, for example, is still to delineate the humid tropics in Africa into major agroecological zones that integrate physical, biological, farming systems, and socioeconomic variables. In such an exercise, each benchmark area may further be delineated into areas where different soil or crop management practices are used for the various crops grown.

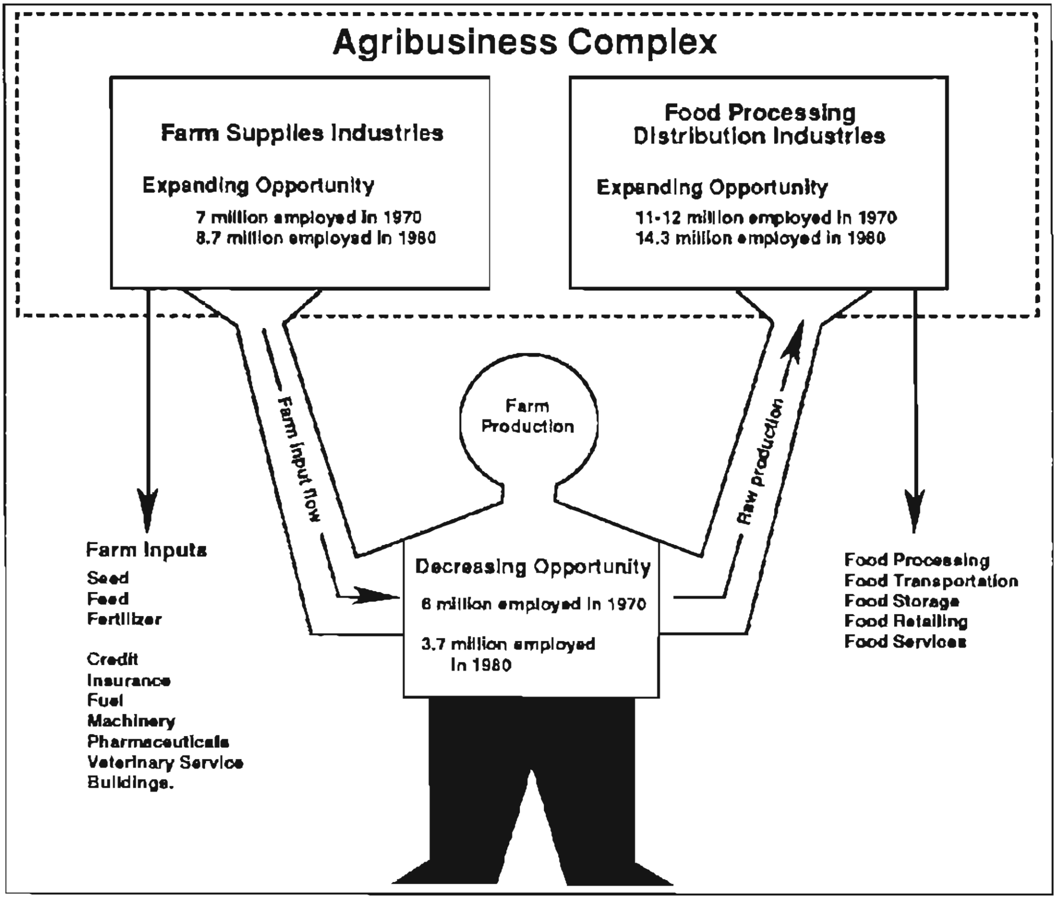


Figure 18. Opportunities for employment and income in agribusiness [Based on data from Snodgrass and Wallace (1970), Robbins (1983), and Delano (1983)].

National-level Planning

Integrated natural resource management, required in sustainable agricultural production, necessitates the evolution as early as possible of a land-use plan on a country by country basis that provides for

- hunting and tourism;
- germplasm conservation and special reserves;
- forestry and forest plantations for fuelwood and timber;
- tree crop plantations;
- special agroforestry systems;
- agriculture, including fallow;
- grazing land;
- urban centers, airports, roads, etc.;
- industry and related uses;
- landscape uses, including parks in urban areas; and
- mining.

This plan could be revised from time to time, as needed. While this is not the concern of IARCs, they can advise on policy. It should be an exercise in which NARS play a major role, and it should also involve laying down legal provisions and measures to ensure compliance.

Use of a Watershed as Development Unit

At the microlevel within each benchmark area, watersheds should be used as units for planning and development. This ensures that different parts of the watershed are developed and used according to land-capability classification and the adaptation

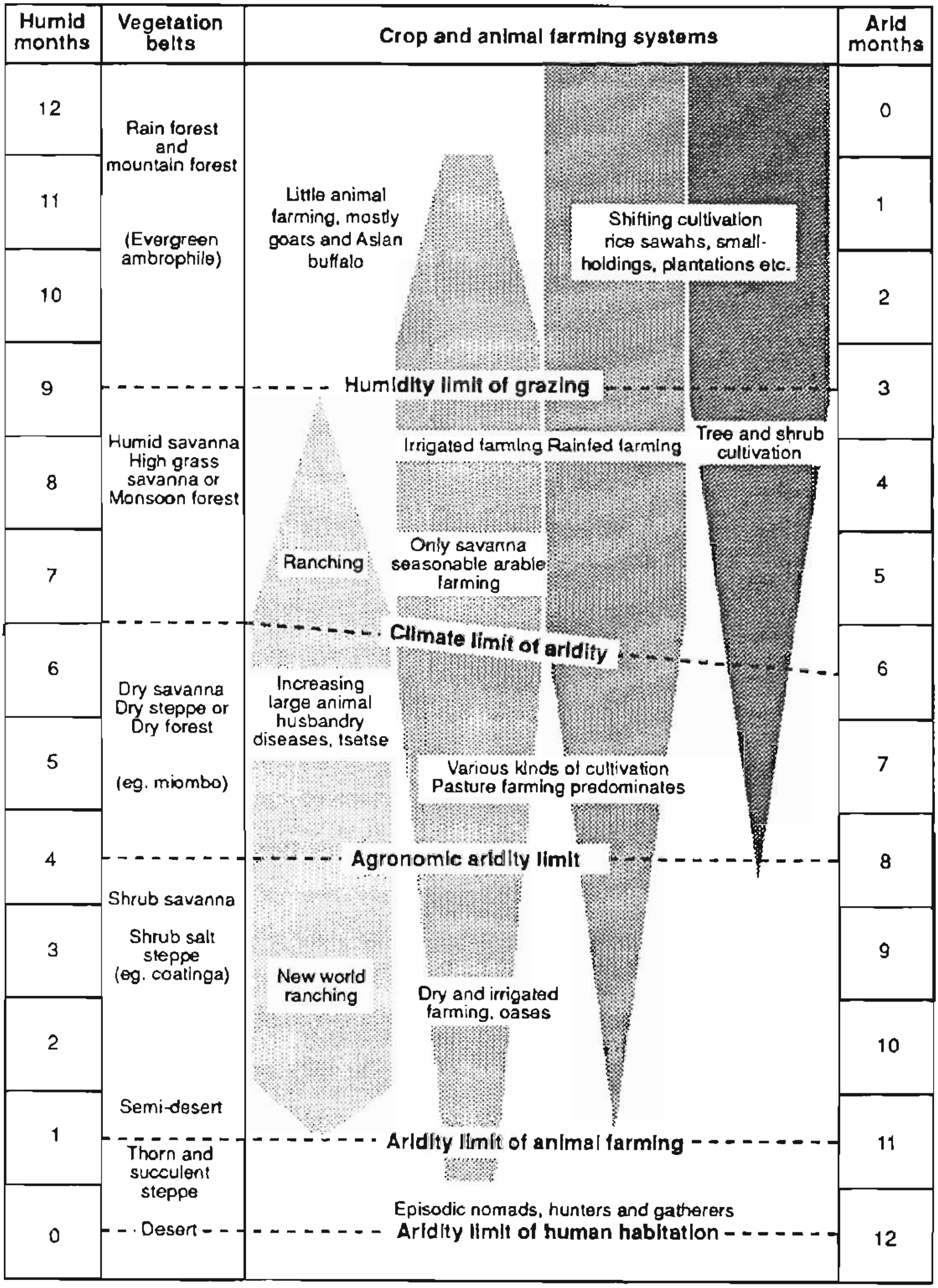


Figure 19. Humid and arid months, vegetation belts and farming systems in the tropics (Adapted from Uhlig 1965, Andreae and Kestner 1980, and Okigbo 1981).

of commodities and systems of production to different parts of the landscape, as shown in Figure 20. The landscape is developed in such a way that it is demarcated into toposequences for use in aquaculture or lowland rice at the bottom, rainfed rice and cocoyam at the toe of the hill, upland crops, agroforestry systems, and pastures or forest at the top. By this method, commodities are grown in the locations where they have maximum ecological and/or economic advantage. IARCs can base more long-term and environmental monitoring rotation studies on this plan.

Strategy for Designing New Cropping Systems, based on Integration of Traditional and Modern Systems

As indicated earlier, the best guideline for the development of sustainable agricultural production systems is for the levels of inputs in high-input systems to be lowered, and for those of low-input systems to be raised in a cost-effective manner. This involves a combination of elements of traditional production systems and their component technologies that make maximum use of biological inputs available locally, with affordable elements of the high-input system. Table 21 lists the various technologies that are used in each system from land development to harvesting and the postharvest phase. Each one of these sets of technologies has environmental implications and consequences in its use. For example, mechanical clearing or burning has adverse effects on the environment, while certain herbicides and methods of weeding may promote erosion. Table 22 indicates the extent of erosion hazard that is associated with each technology or practice at different stages of the food chain. This knowledge could be used during planning and designing to select the alternative practices to be tested.

Need for More Effort In Designing

Francis et al. (1986) outlined a method of planning through progressive biological sequencing of differential cropping systems that involve different levels of internal inputs and external inputs (low-cost, resource-conserving elements and high-input elements) so as to satisfy farmers' needs in a sustainable manner. To use a specific example, it is well known that small farmers diversify crops in traditional farming systems to reduce risk and ensure production of cash and food crops. But traditional intercropping systems make the use of such inputs as fertilizer, machinery, pesticides, etc., often very difficult. The best way of minimizing this problem while maintaining diversity is to:

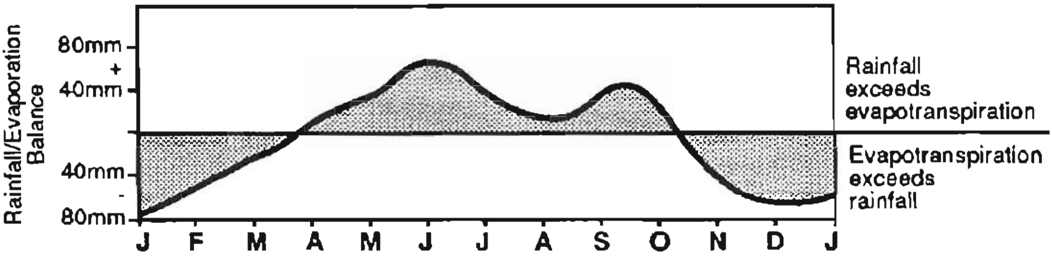
- simplify cropping patterns into simple cropping sequences that may or may not overlap;
- have each area divided into strips of land, so that each strip or plot carries a given cropping sequence; and
- at the end of the year, rotate cropping sequences among strips (the strip of land between two alley-crop hedgerows could be used for one cropping sequence).

This is one likely way for managing alley cropping strips, which could be managed differently in order to achieve different objectives and advantages of the system and minimize the labor involved in canopy management.

Suggested Changes in IARCs' Roles in Research and Training

Changes in Research

The IARCs have traditionally given emphasis to strategic and applied research, while NARS have usually concentrated more on applied and adaptive research. The emphasis on sustainability necessitates both an increased scope of research and increased financial support. To achieve this objective, it would be necessary for IARCs to be more involved in basic research, especially in such areas as environmental monitoring, crop physiology, ecology, geography, etc. This can be achieved through greater cooperation with universities than in the past. This could, at least, be limited to regionally selected universities (see Table 23). As a result of the weakness of NARS and their lack of resources, IARCs need to be involved in aspects of adaptive and development



Illustrates above the pattern of rainfall providing two rainfed seasons and also a potentially more productive dry season if excess rainfall is conserved in tanks (i.e., water harvesting) to extend the growing season.

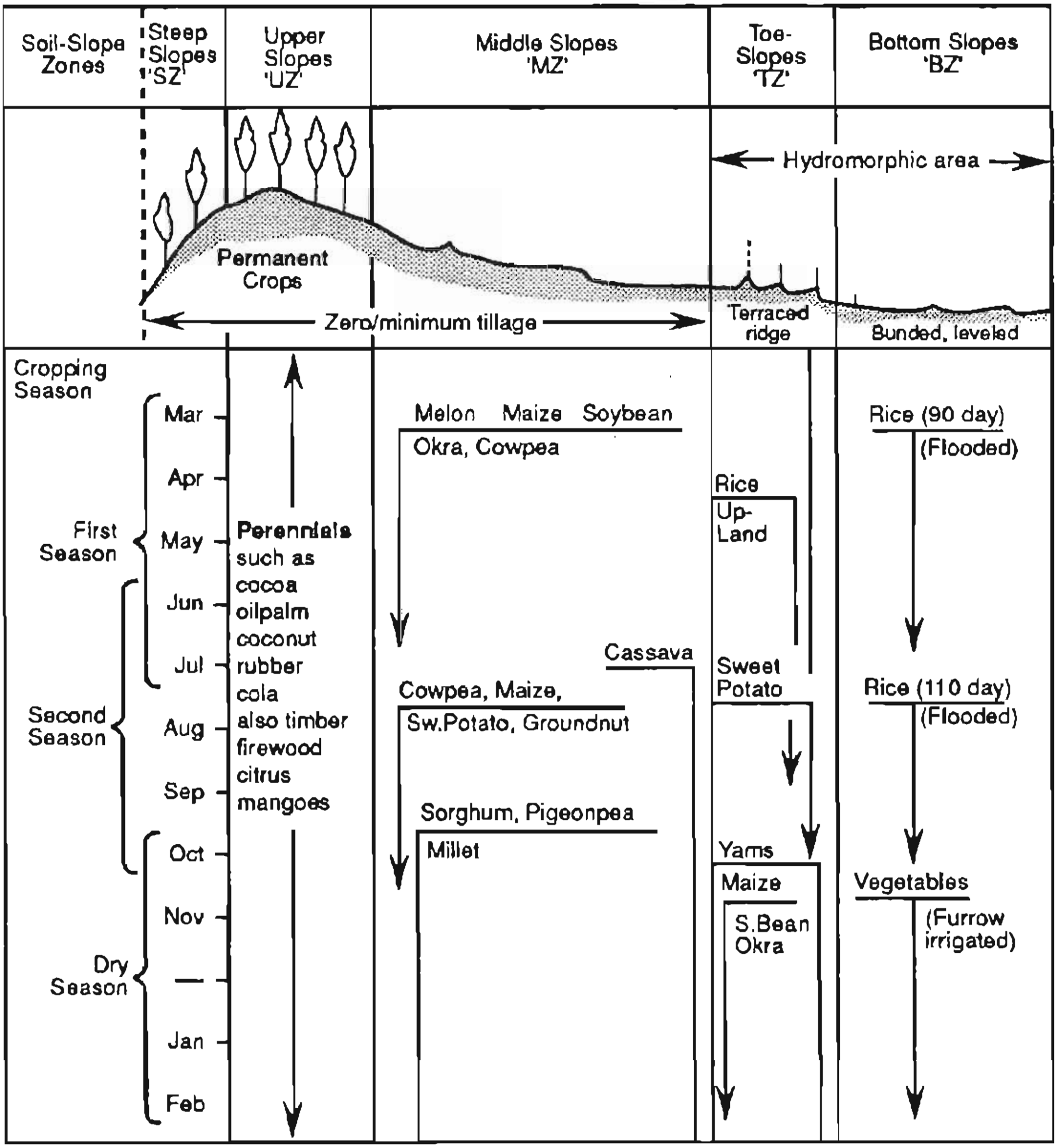


Figure 20. Integrated watershed management (Okigbo 1984).

Table 21. Inputs or technologies used in traditional and 'modern' conventional farming system.

	Traditional Agriculture	Modern Agriculture
Land	Small (< 1-5 ha)	Large (10-100 ha or more)
Tools	Simple: fire, axe, hoe, digging sticks, machete.	Complex, tractors and implements, threshers, combine harvesters, etc.
Crops	Many species (5-80). Landraces, no genetic improvement, wide genetic base.	Few species (1-3). Improved narrow genetic base.
Animals	Several species (2-5)	Usually 1 or 2 species
Labor	Manual, human energy, or animal power	Mechanical, petroleum fuels, electrical energy.
Soil fertility maintenance	Fallows, ash, organic manures.	Inorganic fertilizers, sometimes manures soil amendments, e.g., lime and gypsum.
Weed control	Manual, cultural.	Mechanical, chemicals (herbicides and petroleum-based products).
Pest and disease management	Physical/cultural	Mainly mechanical/chemicals, insecticides, fungicides, bactericides, nematocides, rodenticides.
Crop management	Manual	Growth regulators for defoliation, control of flowering, fruit drop, etc.
Harvesting	Manual or with simple tools	Mechanical—tractors plus implements: pickers, balers, threshers, combine harvesters.
Postharvest handling and drying	Simple sun-drying and over fires	Mechanical forced-air artificial drying using petroleum fuels, sometimes refrigeration.

Source: Okigbo (1988b).

Table 22. **Different operations performed during different stages of crop production and utilization, and the extent of likely erosion hazard involved.**

Operations at different stages of crop production and utilization	Extent of possible erosion hazard[1]
Clearing	Very high*
Land development	High*
Tillage and preplanting cultivations	High
Planting	Low
Subsequent soil management	Low
Water management	Low-high*
Fertilization	Low*
Weeds, pests, and disease management	Negligible to high
Harvesting	Medium to high
Primary processing (e.g., shelling, winnowing)	Negligible
Drying	None
Storage	None
Processing	None*
Packaging	None*
Preparation	None
Consumption	None
Waste disposal	Low-medium*

Source: Okigbo (1986).

1. Extent of erosion hazard depends on interaction of operations with environment and other factors.

* Indicates possible association with environmental pollution.

work, in collaboration with NARS and universities, in so far as this specifically enhances adoption of technologies. Care should be taken to ensure that IARCs are not unduly saddled with more research and related activities that could reduce their effectiveness or dilute their efforts. For example, IITA's work in alley cropping could be made more dynamic by expanding its agroforestry potential in such a way that specific cropping patterns could be tested for:

- alley cropping systems that ensure high fuelwood or poles production with only a slight reduction in food staples production;
- alley cropping systems which incorporate the growing of useful plants that supply raw materials for paper or crafts, along with some food crops;
- alley cropping systems which integrate the growing of food crops with vegetables and fruit trees; and
- alley cropping systems in which different hedgerow species are evaluated for their energy supply potential, with observations on different cooking stoves and/or yield of charcoal and other products.

These will involve more adaptive research than IITA has been used to in the past, but it can be carried out through collaboration with NARS in cooperative development projects.

Changes in Emphasis in Program Objectives and Activities

The sustainability emphasis requires some modifications in the area of IARCs' program objectives and activities. Suggestions in this regard are listed in Table 24. In resource management, for example, there is need for more basic studies of environmental variables, and for the determination of resource characteristics that lend sustainability to a given production system or ensure enhancement of the resource base. Higher priority should be given to energy management as a component of farming systems engineering. An IARC such as IITA cannot afford not to have at least two systems engineers in place all the time. Moreover, economists should be involved in this kind of work and there should be more effective interaction among various disciplines, including social scientists, physical scientists, environmental scientists, agronomists, biochemists, etc., where they are needed in environmental monitoring activities. Much higher priority should be given to systems synthesis evaluation, and to studies of resources interaction in systems and subsystems. More effort should be devoted to systems design testing, and to development of methodologies for evaluating sustainability and contributory factors. The management of interdisciplinary teams, which presently emphasizes development of disciplinary capabilities and peer group status recognition of scientists in their areas of specialization, needs to be balanced with due recognition for their service role in collaborative activities, which is sometimes difficult to evaluate.

Commodity conversion work should expand in scope to encompass primary and secondary processing activities, at least through collaboration with NARS and other agencies, so that nutritional implications of the use of pesticides, for example, could be monitored during the postharvest phase, especially in monitoring pesticide residues and pollution. There is a need for the International Food Policy Research Institute (IFPRI) to assist in developing African capabilities in policy research and training in different regions of Africa. This could be done through location of staff at existing institutions, including universities. The importance of political and administrative institutions in ensuring sustainability, as noted above, necessitates that more emphasis be given to policy.

Strengthening of national capabilities should be given higher priority in the area of research management, and the IARCs need to devise provisions to do this. In this regard, there is a need for IARCs to improve the information and communication services in Africa, including making available all publications free to faculties of agriculture, ministries, and university libraries. In staff development, IARCs and donors should work out methods of collaboration in training to minimize the extent to which dependence is fostered through ex-colonial

Table 23. Modification of research focus necessitated by sustainability emphasis.

	Institutions			
Category	IARCs	NARS	Universities	Special Institutions*
Basic	x ————————————>		x ————————>	x
Strategic	x	x	x	
Applied	x	x	x	
Adaptive	x <———>	x	x	
Development	x <———>	x		

x—> Special institutional collaboration or linkage.

* Includes institutions in both developed and developing countries.

Table 24. **Suggested change in emphasis in various IARC program objectives and activities, engendered by the sustainability emphasis.**

Program objectives	Suggested changes
Resource management	More work on resource interactions. More basic work on environmental monitoring. More work on energy management and alternatives. Greater emphasis on mechanization and systems engineering. Expand scope of involvement of economists and social scientists.
Commodity productivity	Expand work on longer-term evaluation of performance, e.g., rotations and sequences. Expand work on related environmental monitoring. More work on systems design and testing.
Commodity conversion and nutrition	Extend work on range of postharvest technology development and testing. Extend research on nuritional monitoring, through linkages with national and international bodies.
Policy environment enhancement	Need to develop regional center or centers for training and research. Greater focus on certain countries.
Strengthening national institutions	More effort in training, especially in management of research and interdisciplinary team research management. Improve communications with and information service to NARS.
Integrative efforts	Need for more collaboration with selected universities and special institutions.

powers using their institutions in temperate regions to offer courses in such areas as plant breeding, without any period spent in the tropics. There may be a need for two SADCC-like centers in West and Central Africa and the Sahel, where interaction with IARCs can be better coordinated. In this regard, the establishment of the ICRISAT Sahelian Center at Niamey in Niger is timely and a step in the right direction. The sustainability perspective requires more holistic and inter-institutional collaboration, and it should be nurtured through effective collaboration among scientists, programs, and institutions. Unless this is done, the pressure for IARCs to broaden their mandate activities, despite the limited resources at their disposal, will be high.

Other Areas of Emphasis by the IARCs

These could include germplasm conservation and crop diversification, in which priority should be given to conservation, through cooperation with the International Board for Plant Genetic Resources (IBPGR), for work on indigenous African food crops in different regions. This will lend support to extending the range of use of indigenous species in agroforestry systems and in rotations and cropping sequences in which they feature with major staples. More priority should be given to studies of a wide range of agroforestry species and systems, especially in the humid tropics, where their sustainability potential is high. It would be necessary for IITA, for example, to conduct more intensive research on home gardens and agroforestry for various uses, in addition to the present limited work on alley cropping systems for food crop production. There is no reason why various ways of growing food and cash arable crops with oil palms, rubber, or horticultural crops such as papaya (*Carica* *papaya*), mangoes, oranges, and even forest trees for different uses (e.g., *Pterocarpus* spp. for leaf vegetables), including the growing of black pepper on some trees, should not be thoroughly explored. This aspect of agroforestry can be easily executed through collaboration with NARS that are already working on some of these crops. The World Bank is very much interested in this aspect of tree crop production, in which farmers are also often interested.

Bearing in mind that sustainable crop production systems can best be designed, tested, and developed into rotations, the best way of achieving this is through progressive biological sequencing. This involves the selection of crop species and designing of the cropping patterns in time and space to facilitate dynamic cyclical and linear changes in each field environment (Figure 21). The cropping patterns in the different fields (i.e., 1,2,3) are designed in such a way as to facilitate integration of crops and animal production through the interaction of the cropping sequences and the management practices in one field with those on other fields.

Roles of National Agricultural Research Systems and Related Institutions

Sustainable agricultural development cannot be realistically pursued sectorially and in isolation. It must be an integral component of an overall sustainable livelihood and development strategy, which gives priority to better management and conservation of resources so that their use in satisfying human needs minimizes damage to the environment. Consequently, sustainable agricultural development can most readily be achieved as a component of overall improved national resources conservation, which would include their management, production, efficient processing, and utilization. It also necessitates changes in education and training, research and development activities, political and administrative support, as well as institutional changes. A major component of the broad scope of research, the complex problems to be solved, and related training and other activities are all the responsibility of NARS. Suggestions on the role of NARS are reviewed next.

Education and Training

Sub-Saharan Africa is under serious acculturation stress as a result of the triple heritage, referred to earlier. Therefore, there is need for a change of attitudes and values necessary for the development of an environmental ethic, in tune with the current concern about the environment and sustainable development. Most of the traditional conservation and resource management strategies, embodied in various traditional religious practices, culture, and taboos have been disrupted and are no longer functioning. Consequently, there is need for change in the educational system to reflect more knowledge of the environment and the effects of different human activities on the environment. There is also need for more basic understanding of the world around us and especially of Africa's natural resources, in addition to ensuring better agricultural literacy in educational programs and curricula at different levels. This is the best way of making sure that those who in future will shape policy or engage in research or development activities have a suitable background in natural resources and the need for their conservation, as well as their more efficient and rational management and utilization. Also required is a good educational background, which should include a sound foundation in the basic sciences for everyone, no matter what his/her final area of specialization. To ensure this, there is need for review and revision of curricula and courses offered at all levels in the educational pyramid. Associated with these changes should be the upgrading of facilities for training, which ensures development of skills through measures for achieving a balance between general education and vocational training. The deficiencies in general education in African countries are well known, but the concern about environment and sustainability calls for prompt and effective action.

Research and Development

Sustainable development strategies require that research and development activities at

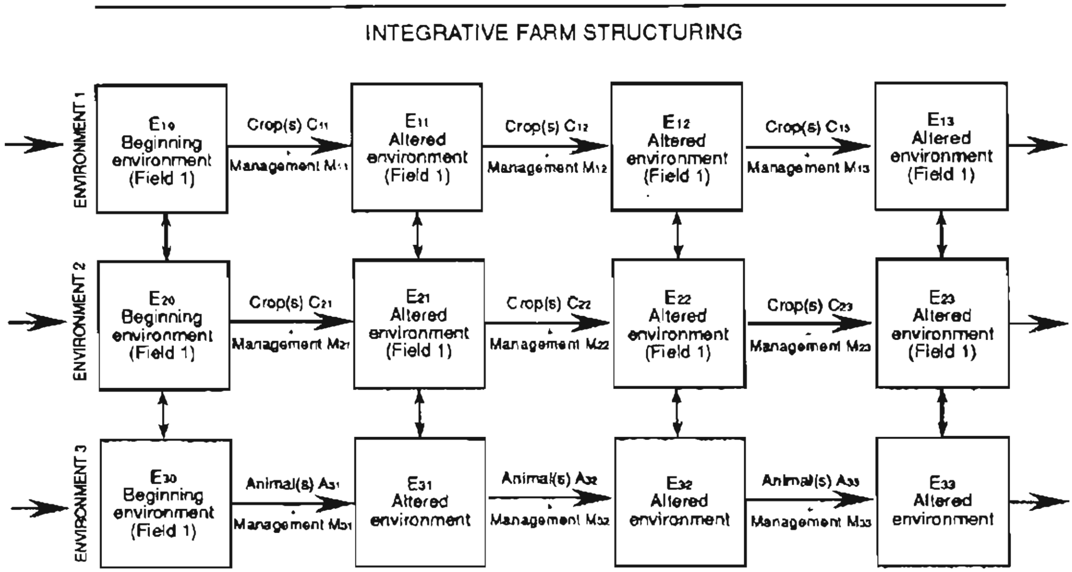


Figure 21. Conceptual framework for designing new crop rotations, showing the pattern of cyclical and linear sequencing in individual fields (1, 2, 3) of successive crops management decisions interacting with each other, through integrative farm structuring. This facilities integration of crops and animal production in highly sustainable mixed farming systems (after Francis et al. 1986).

the national level be strengthened and broadened in scope, to ensure a balance between basic and applied research and development work. In most countries worldwide, universities are the only institutions that are by their nature and provision for academic freedom empowered to engage in all kinds of research and development activities, in which they interact with the more specific commodity and specialized research institutes in the NARS. But in Africa most universities are isolated. There is, therefore, a need to reinvigorate universities in research, to improve their facilities for high-level manpower development, and to provide adequate funding so that they can effectively conduct studies and research in the whole area of natural resources and agricultural production. Sustained research of sufficient scope in the NARS, including universities, is the only sure way of ensuring that NARS take full advantage of developments at the IARCs. It would also ensure that the IARCs' research and training activities, which should grow wider in scope and complexity in order to effectively tackle sustainability problems, are not overstretched and weakened by efforts aimed at making up for deficiencies in the NARS. The IARCs need to concentrate on those aspects of research related to their mandate in which they have the advantage and which require facilities that NARS can hardly afford.

Political, Administrative, and Institutional Changes

At the national and/or regional level, there is need for changes in organization and institutions to ensure greater stability and more effective collaboration in policies, planning, and execution of sectoral development programs. There is also need for changes in policies and provisions, to enhance effective commitment to relevant research and development activities in agriculture and natural resources for sustainable livelihood.

Summing Up

In both developed and developing countries worldwide, there is currently a growing concern about environmental pollution, soil erosion and degradation, loss of genetic diversity, increasing levels of carbon dioxide in the atmosphere, and depletion of the ozone layer. All these changes have adverse effects on man's resource base and the life-support system of all living things. In response to these, there have arisen in different parts of the globe political parties and environmental activists whose major concern is stemming the tide of assault on our resource base and regreening the earth, so as to sustain future generations for millions of years to come, in perpetuity if possible. Sustainability in agricultural production and, in fact, in overall development activities has become a central issue. It is being given priority by the CGIAR, World Bank, development agencies, donors, and so on. Based on a review of several publications, it has been emphasized that sustainable agricultural development in Africa should be considered at the global, regional, national, and local levels, at each of which system components and subsystems also deserve attention. In short, we are dealing with a hierarchy of systems. In addition to the technical and economic issues about sustainability in agricultural production, of concern to the CGIAR and IARCs, there are important political, ethical, moral, legal, cultural, and institutional issues that should be addressed at various levels if sustainability in agricultural production and development is to be achieved. Based on the assessment of the continent's resources, including climate, water, energy, and human, institutional, scientific, and technological capabilities, it is emphasized that more in-depth research, also with a wider scope, is required, especially in the national agricultural research systems (NARS) and to some extent in the IARCs. The need for more effort and resources to be devoted to the planning, designing, and testing of sustainable agricultural production systems, based on an understanding of traditional and conventional resource management strategies and technologies, is stressed. It is further emphasized that there is need for special programs for institutional and manpower development in Africa, for at least another 10 years in the first instance. Observations and recommendations related to these aspects are summarized next.

General Observations

1. The environmental problems of worldwide concern have arisen from different circumstances in developed and developing countries. They raise ethical, moral, legal, and political issues in resource conservation, management, production, processing, and utilization, and they require more prudence, responsibility, and concern about the use of both nonrenewable and renewable resources to satisfy man's real basic needs and the human propensity for material consumption, territorial possession, and domination.

2. The sustainability issue calls for a global ethic and responsibility in the sharing of resources, which is currently heavily skewed against the developing countries. It requires education, reorientation, and a change of attitudes to tackle the problems of resource limitations, environmental degradation, pollution, rapid population growth, and pressures of modernization in as holistic a manner as possible.

3. Sustainable development calls for the redistribution of wealth and effective measures to ensure peace and security nationally and internationally, so that a large proportion of the world's military expenditure of US$1,000 billion, amounting to US$ 2 million a minute, can be used for the provision of basic needs and education to the poor. But how best can this be done?

4. There is fast evolving a global economy and a highly interdependent global community, into which Africa and other developing countries are being drawn at a very fast pace and at a time when these countries are virtually crippled by poverty, heavy debt burdens, poor health, malnutrition, illiteracy, lack of scientific culture, and so on. It is obvious that without a long-term special program of investment in manpower and institutional development, it will not be possible for the continent to develop adequate capabilities in research and development to find solutions to its current problems, let alone attaining sustainability in agriculture and general development that requires a special R & D agenda of sufficient scope, depth, resource allocation, and long-term commitment. There is an urgent need for arrangements to be made to obtain funds for these special R & D efforts from discounts on the crushing debt burdens of African countries.

5. Since sustainability in agricultural production and development is a long-term proposition, the most serious constraint that African countries face in this regard is a lack of stability in political and administrative institutions, which is needed for nurturing development. These institutions are responsible for the policy umbrella, political commitment, planning, program preparation and launching, allocation of resources, monitoring of progress, and coordination of activities in various sectors, including education, research, and extension. It is obvious that unless political stability and support are assured, R & D activities needed for sustainable agricultural development cannot be effective.

6. African countries and their leaders need to know that whatever the stated national policies of developed countries may be on development assistance, each country provides aid mainly on the basis of narrow political objectives and self interest, rather than on the basis of moral obligations and ethical demands for equity. There are also fears in developed countries about development assistance in agricultural research resulting in competition to their export trade in basic staples. Consequently, African countries that continue to depend on foreign assistance for most of their research, training, and extension activities, however committed they may be, are totally unrealistic and are not likely to achieve sustainability in this way.

7. Sustainable agricultural production in Africa can best be achieved as a component of an overall rational natural resources conservation and management program, which minimizes competition among agriculture, fisheries, forestry, industry, and other relevant sectoral activities.

Recommendations

Role of IARCs

1. **Basic Research.** The IARCs need to extend the scope of their research to some aspects of basic research in such areas as environmental monitoring, study of resource characteristics, crop ecology and physiology, crop competition and behavior of organisms which are crucial in the development of emerging technologies, such as integrated pest management. This may be achieved through special collaborative arrangements with universities and specialized institutions in both developing and developed countries.

2. **Adaptive Research.** IARCs should, as a result of weaknesses of NARS in Africa, undertake some aspects of adaptive and development research, in collaboration with NARS, to ensure adoption or commercialization of the technologies they develop.

3. **Agroforestry.** Bearing in mind the fact that in the humid tropics and part of the subhumid tropics, the soils are more prone to degradation and the cost of inputs tends to be higher with row or arable crops, greater priority should be given to the development of agroforestry systems that make good use of trees and shrubs, including fruit trees and plantation crops, such as bananas/plantains, citrus fruits, oil palms, and coffee, in integrated production systems with food crops.

IARCs' Program and Research Activities

1. **Resource Management.** In resource management, priority should be given to resource characterization and the socioeconomic evaluation of resource interaction at different levels and input mixes. Basic studies should be conducted on the behavior of various organisms associated with crops and animals in each IARC's mandate, their life cycles and ecology, to aid the design of integrated pest management systems and various compatible approaches to pest and disease management. Highest priority should be given to efficient energy use and alternative energy sources, especially in association with mechanization and appropriate technologies. This will minimize the continuing reliance, almost exclusively, on human energy, with the associated drudgery in farm work. In this regard, particular attention should be given in the development of improved technologies to the special problems of women.

2. Productivity Enhancement. Priority research activities here should include:

- evaluation of resource mixes and their performance in subsystems and systems;
- evaluation of cropping sequences and rotations, on both short-term and long-term bases;
- environmental monitoring above and below the ground, especially with respect to pesticide residues and contamination;
- expansion of work in alley cropping for specific objectives in addition to food production (e.g., special systems for fuelwood, charcoal, poles production, etc., with the highest priority given to crop diversification in alley cropping systems, especially in the humid and subhumid tropics); and
- integrated watershed and land-use development, where technologies and systems are tested, evaluated for sustainability in small watersheds, and then used for demonstration purposes.

3. Commodity Conservation. IARCs should broaden their scope of research in the postharvest phase of crop production, not only to enhance sustainability of production by reducing losses but also to provide rural employment, while increasing incomes through value added.

4. Integrative Efforts. Despite the number of years of experience in farming systems research and management of multidisciplinary teams, there still appears to be inefficiency in the management of multidisciplinary teams, which are crucial in research with a sustainability perspective. There is need for either offering training in this area or improving the management of multidisciplinary teams, so as to ensure recognition of both peer status in various disciplines and interactive service functions in teamwork.

More effort should be devoted to supporting studies that contribute to the development of integrated pest management, through cooperation among various institutions.

The deficiencies in manpower and institutional development in sub-Saharan Africa necessitate the launching of a special program on manpower and institutional development at levels that will facilitate attainment of the critical mass and excellence to bring about sustainable agricultural production systems in tropical Africa. In this regard, the Special Program for African Agricultural Research (SPAAR) should explore the possibility of launching an effective Africa-wide manpower and institutional development program, for a period of 10-20 years in the first instance.

- There are still many institutions, especially among the ex-colonial powers in Europe, offering such courses as plant breeding for the tropics in Europe. It is recommended that IARCs plan to jointly organize such courses in regional centers in Africa, and thus minimize practices which nurture further increased dependence on countries outside Africa.
- Since many countries in Africa are small and/or poor, it would be most economical to set up regional centers on the model of the SADCC, in Central, Western, and Sahelian African countries for manpower development.

5. Policy Environment. The sustainability perspective in research in the African region and elsewhere necessitates higher priority in research and training to agricultural policy. More efforts should be made to develop local capabilities in the area, by offering courses in regional centers or conducting training in selected universities in sub-Saharan Africa.

6. Germplasm Conservation. There is a need to conserve, at least regionally, the germplasm of indigenous African crops and useful plants, to minimize genetic erosion and extinction. The IBPGR and IARCs may assist in the development of facilities for this in different regions of Africa.

7. Training. In addition to current training programs in the IARCs, the highest priority should be given to research management training, not only for administrators but also for research fellows in M.Sc and Ph.D degree-related research programs. It is suggested that the International Service for National Agricultural Research (ISNAR) explore ways of strengthening training in this area, if possible with the cooperation of the International Center of Insect Physiology and Ecology (ICIPE), which already offers some training in research management.

8. **Interaction with Policymakers.** Because of the importance of political and administrative institutions in ensuring commitment and resource allocation to agricultural research, development activities, education, and training, it is recommended that IARCs make periodic presentations to relevant African policymakers at least once a year. This can be done through OAU/STRC.

9. **Communications and Information.** The NARS in Africa and, in fact, most African research and training institutions remain isolated from the global information networks. Moreover, a lot of new knowledge and new technologies being developed at the IARCs is often unknown to interested individuals in different parts of Africa. It is, therefore, recommended that the CGIAR and IARCs arrange to obtain donor support to have all IARC publications made available free of charge to university faculties of agriculture, libraries, and individuals working on similar problems in Africa.

Roles of NARS and National Institutions

1. **Research, Education, and Training.** By and large, much of the research and development activities of wider scope and complexity, required for ensuring sustainability in agricultural production and development, is the responsibility of NARS, since the scope of their work encompasses crop production, animal production, fisheries, and forestry. In this, the NARS are not as limited by their mandate as are IARCs. It is recommended that at the national level, each country, either alone or in cooperation with other countries, should:

- Review the effectiveness of the educational systems to ensure greater relevance and effectiveness in science and technology, and to incorporate environmental education and nurture agricultural literacy, so that those who become policymakers have the background, understanding, knowledge, and concern needed to ensure long-term commitment to policies and programs for sustainable agricultural development.

- In view of the high levels of illiteracy (up to 70%) among farmers, which hamper technology adoption and minimize the extent of contact with farmers through several media, give higher priority to special adult education programs in rural areas, especially in association with extension work.

- Strengthen research that enhances capabilities in the knowledge of natural resources, their management, processing, and utilization.

- Make more effective use of universities where they exist, since, in cooperation with national research institutes, they not only engage in activities that cover all levels of education but are also in a position to conduct basic, strategic, applied, adaptive, and developmental research, necessary in sustainable agricultural and general development, to an extent far beyond what the IARCs can do.

- Ensure policies, institutional development, long-term commitment, and allocation of adequate resources for the research, development, and training necessary for sustainable agricultural development, through collaboration with the IARCs.

- Allocate some resources to the conservation of germplasm of some indigenous food crops and useful plants within its borders, either in special reserves or in modest, affordable facilities.

- Recognize that fertilizer use in agriculture is imperative, but give priority to research aimed at increasing efficiency of its use, reducing its cost, and minimizing the danger of pollution in its use, by taking advantage of biological processes, such as nitrogen fixation and mycorrhiza that enhance phosphate nutrition.

2. Other Measures for Sustainable Development. To enhance sustainable agricultural development nationally, other measures to be taken should include:

- Improvement of communication among researchers, policymakers, extension workers, and farmers.
- Priority to integrated national land-use plans, as a basis for all sectoral development activities.
- Delineation of the country into major agroecological zones, in cooperation with IARCs and other agencies, so as to ensure that various commodities are grown and their associated production systems used in places where they have ecological and economic advantages.
- Use of watersheds as units for agricultural development planning, with integrated watershed management as a basis for project execution, and adherence to soil capability classification guidelines in selection of sites for growing various commodities.
- High priority to use of small-scale irrigation projects for increased production in drier areas, with emphasis on research that ensures better drainage and water management to minimize salinity problems.
- Measures to ensure greater environmental consciousness in agricultural development and industrial projects, and to provide adequate monitoring activities on a regular basis to guide legislation and enforcement provisions to minimize pollution and environmental degradation.
- Priority to provision of fuelwood in both urban and rural areas, through agroforestry systems that satisfy many objectives, while protecting the soil and producing food and various useful products.

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Annex 1.

A. Some Economic Indicators for Developed and Developing Countries

	Developed countries	Developing countries
Per capita GNP	$9420	$740
Income ratio	40	1
Deaths per 1000 live births	20	120
Life expectancy (years)	71	52
Literacy (%)	>90%	20%
Protein intake (g)	97	54
Number of people per doctor	680	3490
Energy use (percentage of world energy supply)	75	25
Number of countries with ecological problems	17	28

B. Other Indications of Level of Poverty in Developing Countries

Number of malnourished people	800 million
Number of illiterate people	1 billion
Number of children dying annually of hunger and diseases	13 million
Number of people without normal health care	800 million
Proportion of people having access to safe water	2 out of 5
Proportion of people without proper sanitation	1 out of 4
Children not attending school	
(a) 6-11 years of age	30%
(b) 12-17 years of age	60%

Source: Barnaby and Pearson (1988); WCED (1987).