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SUSTAINABLE DEVELOPMENT AND MANAGEMENT OF LAND AND WATER RESOURCES

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SUMMARY

1. An increase in food production of 3% per annum will be required to feed a world population which is growing at 2% per annum - doubling every generation. How production can be increased, while at the same time protecting the environment and the productive capacity of land and water resources, is a vitally important issue.

2. Sustainable agriculture and the sustainable development of land and water resources to increase production where it is needed, are the only ways to avert future human suffering on a large scale. The emphasis on sustainable development responds to growing concern over environmental pollution, global warming, soil and water degradation, loss of biological diversity, excessive dependence on fossil energy and other non-renewable resources, perennial food shortages, and the human and social consequences of neglecting these mounting problems.

3. What needs to be done is well known. The means with which to do it are also known: wise land use based on sound land use planning, efficient use of water, drainage and flood protection, soil and water conservation, improvement in the use of problem soils, and more.

4. What remains is to find arguments and incentives to persuade people to implement such methods. All the protagonists must be persuaded: donors, investment institutions, technical assistance agencies, responsible government departments, technical staff in public and private service, and the land users themselves.

Perspectives and options

5. The ability of land to produce is finite. Important limits to production are set by soil and climatic conditions, available water resources and land use. "Mining" of land beyond these limits results in degradation with decreasing productivity and is non-sustainable. Accordingly, there is a sustainable supporting capacity for any given land area under various input levels. Different strategies are needed for the various ratios between populations, land resources and inputs.

6. Where land and water resources are insufficient to sustainably meet basic human needs with a low level of inputs, the priority must be to raise input levels. For those areas where the resources are insufficient to meet needs even with the use of intermediate or high levels of inputs, the resource base can be enhanced through improvements such as irrigation, reclamation of saline or alkaline lands, drainage and flood protection measures. The economics of such schemes should be compared with the development of other resources as income or foreign exchange earners with which to buy food. The development of resources such as tourism or minerals, or a shift to high-value cash crops on land suited to them, may be of particular importance in areas not appropriate for high inputs.

7. Much of the land remaining for expansion of agriculture is in the humid tropics and has special clearing, fertility and conservation requirements; a lack of infrastructure and services; or poor health conditions. In these areas, there is potential for crops such as rice, cassava and multipurpose trees.

8. Over the years, crops remove large quantities of plant nutrients which must be replenished if crop production is to be increased or maintained. Nutrient enhancement can be achieved by integrated plant nutrition systems which includes the use of inorganic fertilizers, organic amendments and nutrient recycling.

9. Soil erosion can be checked through appropriate conservation and rehabilitation measures using improved land husbandry as the mechanism for encouraging farmer participation.

10. Deterioration of irrigation facilities and weak organizations lead to inefficient water use and decline of production in many irrigation projects. Rehabilitation should deal with strengthening organizations and maintaining them along with the physical structures. Soil salinization needs urgent attention in many irrigation projects. More efficient use of irrigation water and improved drainage systems can deal with this problem.

11. Flooding affects agricultural lands directly and also disrupts the physical and social production system. Besides local mitigation measures, basin-wide or upstream actions are often needed to address its causes.

12. Deterioration of water quality is becoming widespread and is causing a decline in irrigated production in some areas. Farm-level improvements in water, soil and crop management practices will minimize this problem; management of waters of different qualities should be integrated over the whole drainage basin.

13. In the humid tropics, irrigation systems should be designed to eliminate or control the transmission of water-borne diseases.

14. In areas where rainfall does not meet crop water needs for economically viable production, development and management options may include: soil and water conservation measures in rainfed farming; supplementary irrigation, or large- or small-scale irrigation, using surface water in combination with water regulation or improvement of existing schemes, and appropriate water pricing policies.

15. Technological packages for sustainable development of land and water resources should be area specific and must be closely knit within the existing fabric of sound farming practices.

16. Increased agricultural productivity has been made possible through higher inputs of energy, fertilizers, better seed, water and other inputs, and particularly increased knowledge. These trends must also be selectively applied to areas with low-input agriculture if production is to increase and the drudgery of manual labour in low-input agriculture is to be alleviated. This requires more efficient use of inputs and increased investments that are matched by improved marketing facilities.

Suggested action

17. National governments have the primary responsibility for conserving land and water resources. They should formulate policies and legislation, mobilize the people, and plan and implement sustainable agricultural projects according to the priorities and needs of the intended beneficiaries. The identification of priorities

should be based on environmental profiles with clearly defined area-specific entry points (for example, water development in arid and semi-arid areas).

18. The priority areas for sustainable development of land and water resources should be addressed at the grassroots, national, regional, and global levels.

19. **At the grassroots level**, priority should be given to integrated land and water use through appropriate area-specific conservation and development packages backed up by applied or adaptive research. Conservation measures with immediate economic returns should be encouraged. Such a programme exists in Lesotho where the Government, with assistance from FAO and the Netherlands, is helping communities develop and implement their own village conservation and development plans.

20. Equally important are efficient water use and conservation for crop and fodder production; and the management of waterlogging, salinity, drainage and water quality problems. In Nigeria, for example, farmers are practising successful small-scale irrigation using shallow groundwater, supported by effective extension, credit and marketing facilities, through the Bauchi State Agricultural Development Programme.

21. **Nationally**, each country must balance the needs of its present and future populations with its land and water resources, and put the results into a long-term plan of action. This requires political will, sound information, and a strategy of education and persuasion to enlist active support, particularly of the rural land users.

22. Experience shows that strategies should be based on the recognition that land and water development programmes are most successful when they are part of broader area development programmes including infrastructure and services. Farmers and other members of the local community should participate in all phases of planning and development. The National Irrigation Administration in the Philippines, for example, successfully organized farmers into irrigation associations and, with their active participation, solved problems in planning, layout and construction, and operation and maintenance.

23. Putting these strategies into action will involve: land and water management, policies and legislation; development of national institutions, establishment of monitoring and evaluation systems; documentation and dissemination of sustainable technological packages; promotion of information exchange among farmers, agricultural extension staff and researchers; and strengthening of education, training, research and extension.

24. Research, extension and input supply services must be strengthened and well coordinated with each other so that research findings are applied more rapidly and farmers needs are addressed. Emphasis should be given to applied or farmer-level research that will improve the existing farming systems.

25. Governments should develop policies and plans for wise land use and incorporate these into national development plans. These policies should be supported by appropriate resource legislation, based on approaches which balance present and future needs with:

- the national land resources, their potentials and degradation hazards;
- surface and groundwater resources, both in quantity and quality, and existing international water rights and obligations;
- biological resources, both land- and water-based, including their diversity.

26. Institutional frameworks must be in place to monitor, supervise and coordinate action between the different branches of government and other actors involved in land use.

27. Education, training and extension programmes should be mounted to make the public aware of the problem of land degradation and what can be done about it. Links should be strengthened between government institutions and land users, and efforts made to create the socio-economic and institutional conditions which will favour rational land use and management.

28. Regionally, priority should be given to the establishment of regional networks and institutions for information exchange and advanced training. The institutions should document and disseminate, with international support, examples of successful and sustainable soil and water management practices. Governments should intensify efforts to formulate agreements for the allocation and protection of inter-state and international waters as an important requirement for sustainable agriculture. Such regional cooperation is exemplified by the Mekong Committee, based in Bangkok (Thailand) which coordinates the development of the basin's resources on the basis of equitable sharing between states. The Committee has been instrumental in the collection of basin-wide data, the exchange of technologies among member states and the implementation of development projects.

29. Globally, there is a need for coordination of international action: long-term financing can be assured if national governments, NGOs, technical assistance agencies and financing institutions work together to formulate policies and elaborate programmes.

1. INTRODUCTION

1. Sustainable development is the management and conservation of the natural resource base, and the orientation of technological and institutional change in such a manner as to ensure the attainment and continued satisfaction of human needs for present and future generations. Such sustainable development (in the agriculture, forestry and fisheries sectors) conserves land, water, plant and animal genetic resources, is environmentally non-degrading, technically appropriate, economically viable and socially acceptable.

2. Clearly, agriculture and its development are far from sustainable in many parts of the world, both in industrial and in developing countries. Pollution and very high rates of energy use and consumption of other non-renewable resources need to be addressed in the industrial parts of the world. A world population increasing at 2% per year, and more in many developing countries, is not sustainable indefinitely. For the next 50-100 years, however, agricultural production will need to be increased by at least 3% per year to maintain and improve nutrition and health and to enhance the self-reliance of resource-poor land users. How to increase world agricultural production in the right places, while at the same time preserving the quality of the environment and the productive capacity of land and water resources, is the most important issue of our time.

3. Sustainable agriculture is not necessarily synonymous with low input, organic, regenerative or alternative agriculture. In some cases, with relatively fertile soils and favourable climate, off-farm inputs can be reduced by adopting labour-intensive and skilled technologies. These technologies include mulch farming, agroforestry, use of organic manure, appropriate crop rotations and in-situ water conservation. In others, such as in sub-Saharan Africa and some other tropical regions, low-input and subsistence farming has been an economic, ecological and socio-political disaster. The addition of organic amendments may enhance soil productivity but may not eliminate the need for balanced fertilizer use because large amounts of plant nutrients are required in easily available form to produce economic returns. Pest incidence may be reduced through crop diversification and other cultural or biological practices; but chemical compounds may be a necessary weapon in the arsenal of pest suppressing-tools for an efficient and sustainable agriculture. The terms "low input" or "no input" should not, however, be confused with lack of innovative technologies. The objective is to minimize rather than eliminate purchased inputs.

4. In addition to ecological and economic issues, sustainability also has social and political dimensions. People must not only survive biologically from agriculture but also derive an acceptable lifestyle. In developing countries with subsistence farming, agricultural practices must alleviate suffering from human drudgery. Agricultural technologies must restore respectability of the agricultural profession. Small returns because of impoverished soils, unreliable rainfall, and inadequate amounts of purchased inputs have been responsible for low standards of living and widespread malnutrition in the tropics and sub-tropics. In these situations, an important strategy to reverse the degradative trend and transform subsistence

and resource-based farming into sustainable, market-oriented agriculture is to increase the use of off-farm inputs, e.g. fertilizers, irrigation, labour-saving tools, input-responsive improved varieties. Perpetuating low-input agriculture in these conditions is a not a solution.

5. Each country will need to use a balance-sheet approach to match the needs of its present and future populations with the potentials of its land and water resources under different input levels, and build a long-term plan of action on the results.

6. While land resources and most water resources are **renewable**, they are **not replaceable**. Traditional discounted cash flow considerations fail to take into account the intrinsic increase in value of any given renewable natural resource for humanity. Unlike most works of man which decay with time and should be subject to write-off besides discounting, a natural resource of necessity becomes more precious as populations increase.

7. The making and execution of a sound long-term plan of resource use and conservation requires political will, reliable information and a strategy of education, persuasion including incentives, and strengthening of institutions, in order to enlist the active support particularly of the rural land users.

2. NATURAL RESOURCES AND FUTURE DEMANDS

8. As recently as the seventies, a considerable proportion of the increase in food production was achieved by bringing new land under agricultural production. Presently, however, reserves of potentially arable prime agricultural land are hard to find. Furthermore, land resources are unevenly distributed. Much of the potentially arable land is located in regions with robust economies, e.g. North America. Densely populated Asia, home to 75% of the world's population, has little additional land to convert into arable use. Similarly, comparatively little is available in Europe. There is a possibility of an additional 200 million hectares in North America, almost 300 million hectares in South America and more than 300 million hectares in Africa (Revelle 1976; Buringh 1989; Dudal 1982).

9. Bringing new land under production through the clearing of tropical rainforest has severe ecological, environmental and socio-political implications. The actual extent of deforestation in the tropics is still the subject of debate. In addition to loss of biological diversity and potentially valuable genetic resources, conversion of tropical rainforest presumably contributes a large proportion to total global emissions of CO_2. However, the exact amounts are not known. The type, amount and rate of gaseous emission also depend on the method of deforestation. The effects differ among techniques, e.g. slash and burn, chain-saw clearing, deforestation by bulldozers and chemical poisoning of trees. The effects also differ among different land uses following deforestation.

10. Most of the available land in Africa and South America is located within fragile and ecologically sensitive regions, e.g. tropical rainforests, acid savannas, the drought-prone Sahel. Large proportions of the presently cultivated land are not compatible with

sustainable agriculture. Much of the potentially productive agricultural land is either inaccessible, too steep, too shallow, or is in regions with too little or too much water, and essential inputs for crop production are not available.

11. If the arable land area is maintained at 1.45 billion hectares, the per caput arable land will progressively decline from about 0.3 ha now to 0.23 ha in 2000, 0.15 ha in 2050, and 0.14 ha by the year 2100. These calculations are based on the assumptions that neither new land is brought under cultivation nor existing land goes out of production due to degradation.

12. The latter assumption, regrettably, is not correct. At present 5-7 million hectares of arable land (0.3-0.5%) are lost every year through soil degradation. The projected loss by the year 2000 is 10 million hectares annually (0.7% of the area presently cultivated). The world is now losing more than 20 billion tons of top soil per year from uplands in excess of new soil formation (Brown 1981). By the year 2000, productivity of about one-third of the world's arable land may be severely impaired due to accelerated erosion (UNEP 1982). There are about 323 million hectares of salt-affected soils in the world (Beek et al, 1980). Mabbutt (1978) and UNEP (1984) estimated that a total of 3.8 billion hectares are prone to desertification.

13. The minimum dietary requirements per caput can be met from an average of 0.14 ha of arable land, through technological innovations that may bring about a quantum jump in food production. FAO (1984), through its agro-ecological zones project, estimated that, in 1975, 38 percent of the total land area was carrying more people than could be fed at low-input level. In comparison, 22 percent of the total land area was carrying more people than could be fed from rainfed agriculture and existing irrigation, even with high input.

14. The land-population scenario should be assessed in terms of four challenges. The first, not discussed here, is population growth itself. Secondly, the uneven distribution of land resources. Population-supporting capacity of the land is not a problem in North America, Europe or Australasia. Thirdly, low available land reserves and poor resources to use high-input technologies of regions with high demographic pressures. Several countries of South Asia and Central America under this category are also characterized by severe rates of land degradation. Fourthly, socio-economic, anthropological and political considerations are often overwhelming and do not readily permit the adoption of improved technologies. Under these conditions, low-input technologies become an integral part of a vicious cycle of poverty-malnutrition-soil degradation that must be broken to free its victims: an estimated several hundred million people (Griggs 1985).

15. Irrigation played a major role in increasing food production during the 50 year period ending in 1990. The world's irrigated land was 8 million hectares in 1800, 48 million hectares in 1900, 94 million hectares in 1950, 182 million hectares in 1973, and 229 million hectares in 1988. Presently, irrigated land accounts for one-sixth of the cultivated land but produces one-third of the world's food (over twice the productivity of average rainfed land). However, the current rate of expansion has slowed to less than 1% per year. Both availability of additional irrigable land and good quality water are severe constraints to further expansion.

16. In developing countries as a whole, only 4% of total commercial energy is used for agriculture and merely 2.7% is in the form of fertilizer. Mineral fertilizer use on arable land ranges from 100 to 800 kg/ha in industrial countries compared with 4 to 50 kg/ha in most developing countries. Increasing use of fertilizers and other agricultural amendments is limited due to restricted availability and high cost of non-renewable sources of energy. Low-cost, renewable hydro-electric power is available only in a few countries. About 70 percent of the world's nitrogen fertilizer is produced by using natural gas as the source of feedstock and energy. Similar to population and land resources, natural gas deposits are also unevenly distributed. Most countries without natural gas have to import nitrogen fertilizers.

17. The intensification of agriculture is faced with severe risks of environmental pollution. The so-called "greenhouse effect" is directly linked to agricultural activities, and soil-related processes play a major role in emission of greenhouse gases. World soils contain more carbon as soil organic matter than world biota or the atmosphere. Intensive land use for seasonal crop production may lead to depletion of soil organic matter and release of carbon dioxide into the atmosphere. Pollution of surface and ground water by agrochemicals is another major environmental hazard. A large proportion of fertilizers applied is susceptible to volatilization, removal in surface runoff or eroded soil, or leaching into the ground water. The annual discharge from agricultural lands, including woodland, pasture and rangeland, to waterways in the USA is estimated at one billion tons of suspended solids, 0.48 billion tons of dissolved solids, one million tons of total P and 4.7 million tons of total N, presumably part suspended, part dissolved (Duttweiler and Nicholson 1983). Although soil erosion is equally, if not more, severe in developing countries, reliable estimates of its extent and rate are not available. There is equally great concern about the contamination of surface and ground waters by water-soluble pesticides, such as aldicarb, ethylene dibromide, and atrazine. Pesticide use is rapidly increasing in developing countries. However, drinking water supplies are scarce in many places, rarely treated, and seldom tested for contaminants.

18. Despite the problems outlined above, agricultural production must be increased, in several cases substantially and immediately. Yet the countries with an urgent need to bring about the quantum jump in agricultural production are also victimized by the vicious cycle of poverty, low-input agriculture and soil degradation. This cycle can only be broken by transforming resource-based, low-input farming into science-based agriculture. The latter must be based on the judicious use of off-farm inputs, because high productivity depends on inputs. The more impoverished an ecosystem, the more inputs are needed to raise economic output. During the past decade, for example, fossilfuel input in Chinese agriculture rose 100-fold, and crop yields tripled (Lu et al, 1982). The comparatively low output of Indian agriculture is due to low input of energy, 0.14 tons/yr/per caput coal equivalent in India compared with about 5 tons in UK and over 10 tons in USA.

19. With low or medium input, the minimum dietary requirement can only be met from about 0.5 ha land per caput. The greatest challenge facing mankind in the 21st century is to produce the basic necessities of food, feed, fiber, fuel and raw material from 0.14 ha land per caput, or less. Technological options for sustainable management of soil and water resources in the 21st century must address this issue. The per caput land requirement to meet the basic needs depends on the inputs. Buringh (1989) presents an optimistic scenario. He estimates various modes of agriculture and the per caput land requirement for each mode (Table 1). The average per caput land needed under different systems and corresponding crop yields vary by two orders of magnitude. Two of the most encouraging aspects of this analysis are: that per caput arable land area can be as low as 0.11 ha or less at a moderate level of technological inputs, and that about a quarter of the world's cropland is suitable for intensive use through adoption of moderate, high or specialized technologies. The relevant concerns are how to identify and address appropriate issues for different ecological regions, develop and adapt technological options for sustainable use of soil and water resources, transfer the best management and proven technologies, and provide incentives to farmers to adopt these technological innovations.

Table 1. Yield in grain equivalents and percentage of cropland for various levels of production input in the world

Farming system/ input level	Yield t/ha	Cropland (%)	Average area of arable land needed (ha/caput)
Shifting cultivation	< 0.1	2	2.6
Low traditional	0.8	28	1.2
Moderate traditional	1.2	35	0.6
Improved traditional	2	10	0.17
Moderate technological	3	10	0.11
High technological	5	10	0.08
Specialized technological	7	5	0.05

3. ISSUES

20. Despite the potential for enhancing food production, it is clear that the world's arable land resources are finite. Out of the 22% of the earth's surface area that is agriculturally suitable, 13% has a low productive capacity, 6% a medium, and only 3% is characterized by a high capacity for intensive crop production (Buringh 1989).

21. Rapid population increase in itself is another major cause of land scarcity. About 80 million people are added to the human population per year. If an average of 0.1 ha is needed per caput for accommodation and living, about 8 million hectares of arable land would be converted annually to non-agricultural purposes; much of this will be from agricultural land.

22. The limited availability of good-quality water resources is becoming a major production constraint in an ever increasing number of countries. Only 2.5 percent of the world's water is fresh water, and only a fraction is available for agricultural purposes. Nearly 80% of the total annual global precipitation falls over the oceans. Of the remainder, 64% evaporates, leaving a mere 8% for surface runoff or ground water (Hall 1989). In addition to the low total amount, rains in many regions are highly irregular and seasonal in character. Worldwide, some 17% of the cropland is fully or partly irrigated. In sub-Saharan Africa, only 4% of the cropland is irrigated. Further expansion of irrigated land is severely constrained by lack of water.

23. The scarcity of water resources is exacerbated by the loss of irrigation water in supply systems and on the farms. Many irrigation systems are operated at efficiencies below the accepted standard of 50 to 60%, implying that half, or more, of the water available at the source is not used by the crop. Though part of the losses in some of the irrigation systems may be recovered by pumping from the groundwater or from rivers downstream, raising irrigation efficiency remains a major challenge. Agriculture in many countries is based mostly on irrigation, e.g. all of the farmland in Egypt, 72% in Pakistan and 67% in Japan is irrigated. Despite intensive use of irrigation in several countries, the per caput irrigated land in the world is less than 0.05 ha.

24. The scarcity of land and water resources, and the growing population pressure are at the basis of a variety of degradation problems. Some of the major issues are briefly reviewed below.

DEGRADATION OF LAND RESOURCES

Soil erosion and siltation

25. Accelerated erosion by water is a serious problem in several ecologically sensitive regions, e.g. the Himalayan-Tibetan ecosystem, the Andes, the Caribbean, eastern Africa and other densely populated regions with severe land shortage. Steeplands, comprising a large percentage of the total land area in these regions are over-exploited and mis-used. Siltation of irrigation channels and reservoirs, as a result of erosion, has become a major problem in water supply and distribution systems. Erosion in the loess plateau of China has been raising the bed of the Huaihe (Yellow River) by as much as 10 cm annually. Most of the Near East and Africa north of the equator are subject to accelerated erosion.

26. Uncontrolled and excessive grazing is responsible for depleting vegetation and denuding the landscape, causing soil compaction and hard-setting, accelerated runoff and erosion. Grazing can cause degradation even if the stocking rate is moderate or low. Perrens (1986) reported that in Australia 55% of the total grazing area of 3.4 million sq km in arid regions needs restorative measures due to land degradation.

27. Wind erosion is severe in arid and semi-arid regions. In southern Tunisia, wind erosion rates of 10 mm of topsoil removed per year are common; windblown dust from the Sahara causes air pollution and "sand-rains" in northern Europe (Le Houerou, 1977b). The global rate of desertification is estimated at 6 million ha/yr.

Soil fertility depletion

28. Many soils cultivated by shifting cultivators and subsistence farmers in the tropics and sub-tropics are subject to fertility depletion through decline in soil organic matter, reduction in nutrient reserves by crop removal, leaching and acidification. Leaching and acidification are serious problems in soils of seasonally or perennially tropical climates. Substantial areas of acid tropical soils occur in Sumatra, Malaysia, the Congo and Amazon basins, and the Cerrados and Llanos of Brazil and Colombia. Nitrogen is most readily lost, and the extent of loss can be as high as 60 kg/ha/yr from cropped land and 300 kg/ha/yr from uncropped land (Suarez de Castro and Rodriguez, 1958).

29. With the present level of world yields, the annual amount of harvested plant nutrients in 3 major cereals (rice, wheat, corn) is estimated at 40 million tons of N, 15 million tons of P_2O_5, and 28 million tons of K_2O. There are several strategic issues that need to be resolved. Can N fertilizers be synthesized and other essential plant nutrients (P, K, Zn, S, etc.) mined and manufactured with available reserves of fossil fuels? Are there alternate sources of fertilizer or power to meet the needs of tomorrow's agriculture? Are organic manures a viable source of the plant nutrients required to supply world agriculture? Pimentel (1989) estimates that only 2.5% of N in the manure is recoverable and usable with present technology. The losses of N from organic manures (30-90%) by volatilization and leaching are a major source of water and atmospheric pollution.

Waterlogging and soil salinization

30. Waterlogging and soil salinization are major causes of declining yields on irrigated land. Salt-affected soils are widely distributed throughout the arid and semi-arid regions. Although many have a natural origin, human intervention has often accelerated their formation. They largely result from water losses in the irrigation distribution system and during field application, causing saline groundwater to rise into the root zone of the crops. The problems are particularly severe in China (where 7 million hectares are affected), India (20 million hectares), Pakistan (3.2 million hectares), and the Near East. However, they are not limited to developing countries: they also occur in the USA (5.2 million hectares) and in southern European countries.

Atmospheric pollution

31. Soil degradation and atmospheric pollution go hand-in-hand. Atmospheric concentrations of CO_2 and other gases have been steadily increasing over the last century or more. Terrestrial ecosystems play an important role in the global carbon budget. In addition to the effects of deforestation, it is now widely believed that world soils play an important role in the global carbon budget. Soil misuse and over-exploitation, causing rapid depletion of soil organic matter, can lead to emission of greenhouse gases into the atmosphere. Lal (1990) estimated that reduction of about 1% in organic carbon content of the top 15-cm layer of soils of the tropics can lead to an annual emission of about 128 billion tons of C into the atmosphere.

DEGRADATION OF WATER RESOURCES

Deterioration of surface and groundwater quality

32. Water quality has been deteriorating rapidly, particularly during the past two decades, as a result of many development activities including agriculture. This has affected not only agriculture, but also drinking water supplies and industry.

33. Besides contamination by heavy metals, industrial chemicals and agrochemicals, salinization of fresh water is expected to be one of the main water-quality problems in the nineties. It may arise by evaporation, discharge of saline waters into rivers, sub-surface flow of saline water into surface and groundwater sources. Salinization of coastal freshwater aquifers through over-extraction and consequent salt-water intrusion from the sea is a major threat. Aquifers are

polluted with nitrate from excessive fertilizer or manure applications. Surface waters receiving excess nitrate, and phosphate, may become depleted in oxygen by massive growth and decay of algae which, in turn, may cause fish kills and release of toxic substances.

Flooding

34. Large areas of cultivable land are susceptible to periodic flooding. Most of the territory of Bangladesh (80%) was flooded during the monsoon rains of 1987 and 1988 with a heavy toll of human lives, loss of crops, and destruction of infrastructure. Such events have gained in intensity due to the reduced water retention capacity of deforested areas and eroded soils upstream. Though individual floods cannot be predicted, much can be done to protect the population and to reduce damage by suitable land use and management upstream.

Vector-borne diseases

35. Vector-borne diseases have been among the most important health problems worldwide for many years, unfortunately associated with irrigation development. Despite progress made in their control during the past decades by use of insecticides, they still represent a constant and serious risk to a large part of the world's population. The improper construction and management of irrigation schemes has in many cases led to an increase of malaria, schistosomiasis and other vector-borne diseases, particularly on the African continent. Measures to control these diseases in agricultural development projects do exist, particularly preventive environmental management measures. These need to be incorporated from the very beginning of the planning phase for an irrigation project.

SOCIO-INSTITUTIONAL ISSUES

36. Technical issues such as those discussed have their roots in human behaviour and in the institutions through which actions are channelled. Social and institutional issues need to be addressed to allow practical solutions to technical problems. Obstacles have systematically occurred in the following critical areas.

37. Many of the problems that arise from low farm income have their origin in the inefficiency of existing institutions to provide farmers with the required support, for example in the form of credit, market information and channels, and applicable research results.

38. Active farmers' associations are a pre-condition for the effective implementation of soil and water conservation programmes under rainfed conditions. To convey the appropriate technologies and implement them, strong and well-trained extension services are required.

39. Inefficient water use at the farm level is one of the major causes for soil salinization and low yields. Farmers need training for efficient water use but extension services are often weak and not well prepared technically to provide the necessary assistance.

40. Deterioration of the irrigation infrastructure is largely due to inadequate farmers participation insufficient financial resources and poor management of the system. Unrealistically low water rates and lack of consistency in their application is also a major problem in obtaining sufficient revenue for proper upkeep of the systems.

41. The development of small-scale irrigation offers considerable potential but, to be able to function in an independent manner, strong water-user groups should be established and the required technical assistance provided to users who may be dispersed and located in remote areas. This points to the need for strong irrigation institutions to stimulate the establishment of water-user groups and to provide the necessary assistance.

4. TECHNOLOGIAL OPTIONS

42. Traditional farming - labour-intensive and resource-based - is environmentally sustainable as long as human and animal population pressure is low, and yield expectations are not high. The system is workable if: a favourable soil structure is maintained; soil erosion is controlled; nutrients are effectively recycled, through ash in the case of shifting cultivation; seasonal crops are grown in association with deep-rooted perennials; pests are kept under check through rotation and diversity; and food-security is guaranteed by mixed and multiple cropping. In the past, most of these requirements have been met through low cropping intensity based on lengthy forest or bush fallowing. Until the last three or four decades, population densities were low, and food needs and basic necessities were met through cultivation of food staples grown in association with trees, other woody perennials, and some animals. Farm size was limited to what could be comfortably managed by family labour. The success of the system was attributed to a limited number of people living on sufficient land to provide a subsistence way of life. Now, however, the pressure from increasing human and animal populations, lack of sufficient land for lengthy fallow, lack of off-farm purchased inputs, rapid soil degradation, low yields and dwindling returns, and higher aspirations are making the system non-sustainable.

REQUIREMENTS OF A SUSTAINABLE SYSTEM

43. Creative and sustainable agricultural technologies must promote a symbiosis between humans and the environment. Sustainable technologies must conform to and address the specific ecological constraints and long-range consequences of simplification of the complex, diverse natural ecosystems. Sustainable development must address the issue of ensuring food supply, enhancing soil productivity, preserving environmental quality, and transforming subsistence farming into economically viable commercial agriculture. The latter is possible only if the size of the farm holding is economically viable and if supporting agro-industries are developed to absorb labour displaced by transforming labour-intensive farming into a science-based commercial enterprise. For an agricultural system to be sustainable, it must have the following characteristics:

Increased energy flux

44. The overall energy input and output must be regulated to enhance biological yield versus production inputs. Both energy efficiency and flux need to be increased as population pressure grows. The energy efficiency of a higher-input system can be improved by reducing nutrient losses caused by leaching and erosion, and enhancing nutrient capital through judicious inputs of mineral fertilizers and organic amendments.

45. Local-specific research is needed to ensure an adequate supply of nitrogen for the desired level of yields through input of mineral fertilizers supplemented by other sources of nitrogen, e.g. symbiotic nitrogen fixation through legume-based rotations and agroforestry systems, organic manures and composts, azolla. Similarly, the productivity of soils notably deficient in P can only be enhanced through substantial and regular additions of phosphatic fertilizers. The efficiency of fertilizer use can be increased by use of new cultivars, and through mycorhizal mineral infection.

46. The use of fertilizers is necessary, but its rate of application can be minimized through better systems of soil, crop and water management. Efforts to increase and sustain agricultural production by adding mineral fertilizers alone, without improved and efficient systems of soil and crop management, are bound to cause frustrations and disappointments. The judicious combination of both management and inputs is crucial to a sustainable development of agriculture. Drastic changes towards more sophisticated farming systems may not be feasible at least in the short term in several ecological regions. Some moderate improvements in traditionl farming systems may be the first step towards modernization.

Low drudgery and high dignity

47. Agriculture must be a respectable profession devoid of undue drudgery and misery. The approach adopted should be dynamic to introduce labour-efficient technologies. The new technologies may be based on animal power or motorized farm operations with a varying degree of mechanization. The scientific community, including social scientists and anthropologists, must address the issue of human values and dignity. Tilling land by hand tools, controlling weeds by a back-breaking hoe, threshing grains by beating with a stick or trampling by human and animal traffic under life-long poverty, is not an inspiring profession. Concern about over-dependence on non-renewable fossil fuel is genuine but not a justification for condemning resource-poor farmers to the perennial hardships of such operations.

Less dependence on rainfall

48. Insufficient water supply is the most important single factor governing agricultural production in arid and semi-arid regions. Irrigation potentials are not well defined in a number of countries, e.g. in sub-Saharan Africa. Runoff in many African river systems is low, and ground water aquifers are meagre compared to the vast rechargeable reserves in the Indus and Ganges valleys. Large-scale irrigation schemes, similar to those of South Asia, are very capital-intensive. For this reason, the development of small-scale irrigation schemes should be given increased emphasis. Soil management techniques for water conservation and water harvesting or recycling, in combination with supplementary irrigation, are needed to reduce risks of crop failure and increase yields.

Soil rehabilitation

49. Improved subsistence farming and increased production, sustaining the higher level of net output and preserving the productive potential of natural resources can be realized through restorative measures of soil and crop management. The soil's productive capacity must be preserved and improved by preventing soil erosion, promoting activity of soil fauna, improving soil organic matter content, and by

replacing the nutrients harvested in crops and animals through mineral fertilizers and organic amendments supported by effective nutrient-recycling mechanisms.

50. The productive efficiency of a system must be evaluated in terms of its effect on the natural resources, e.g. change in soil organic matter reserves, pH, plant nutrient reserves, exchangeable cations, plant-available water capacity or effective rooting depth. Suitable farming systems enhance soil quality. Fertility-mining and soil-degrading, low-input systems must be replaced.

Ecological compatibility

51. Simplified agricultural ecosystems may have high productivity but are often more susceptible to environmental stresses than natural ecosystems. The objective of sustainable management is to minimize the vulnerability of these systems to degradative effects of accelerated erosion, rapid depletion of soil organic matter and nutrient reserves, and excessive build-up of unfavourable flora and fauna. Risks of instability or fragility created through simplification of an ecosystem should be minimized through appropriate soil and crop management.

COMPONENTS OF SUSTAINABLE SYSTEMS

52. For areas with high or moderate population pressure, extensive agricultural systems based on fertility-restoring measures involving shifting cultivation or bush fallow rotation are no longer economically viable or ecologically compatible. There are several proven sub-systems or components that can be used as building blocks for formulating sustainable systems for a range of agro-ecosystems. Local-specific and on-farm validation is needed in adapting this information. There is also a need for creating new knowledge through biotechnology and other modern innovations. Some components or sub-systems are discussed below.

Nutrient management

53. Highly-weathered tropical soils (Ferralsols, Acrisols, Nitisols) having inherently small nutrient reserves, must have a regular nutrient supply for intensive production.

54. Although crop production can be increased by increasing fertilizer use, many small landholders and resource-poor farmers cannot afford the costly fertilizers. Policy makers and economic planners must develop a long-range strategy to ensure a dependable and timely supply of mineral fertilizers at affordable prices. Over-dependence on mineral fertilizers and other agro-chemicals must be avoided for economic reasons (the costs of such a strategy are prohibitive for the small farmers of the tropics) and to protect the environment. Integrated plant nutrition systems involving a combination of mineral and organic fertilizers constitute a useful strategy to minimize dependence on mineral fertilizers, and enhance soil structure and physical characteristics. The rate of application of fertilizers can also be reduced by minimizing losses and increasing recycling of nutrients. Losses by volatization, leaching and erosion can be controlled through conservation tillage, timely application by split doses, fertilizer placement and slowrelease formulations. Technological options for nutrient recycling include crop residue

management and mulch farming, legume-based rotations, ley farming with low stocking rate and controlled grazing, and agroforestry systems including alley cropping.

55. Nutrient recycling mechanisms can work only if there is something useful to recycle. The system is ineffective in highly weathered Ferralsols and Acrisols, which are virtually devoid of basic cations and contain predominantly exchangeable aluminium and some manganese in the subsoil. There are some advantages in supplementing nitrogen fertilizers by biological nitrogen fixation. The economics of growing nitrogen versus buying nitrogen have to be carefully evaluated in terms of time, land scarcity, and efficiency of the nitrogen produced or added.

Soil conservation

56. Soil erosion control is crucial to sustainable management of soil resources. Taking the pressures off marginal lands is the best solution for the control of accelerated erosion. Intensive cultivation of prime agricultural land, creating off-farm employment and developing income generating capabilities are important options. Above all, there are several options for erosion management even on prime agricultural land. The choice of an appropriate option should be carefully made with due consideration of soil types, land form and terrain characteristics, rainfall regime and hydrology, farming system, and socio-economic factors.

57. Erosion-prevention measures enhance soil structure, decrease raindrop impact, improve infiltration capacity and decrease runoff rate and amount. These measures form part of soil and crop management systems such as mulch farming through cover crops and planted fallows, multiple cropping, multi-storey canopy systems and conservation tillage. Conservation tillage systems are generally reduced tillage systems that eliminate or decrease frequency of soil inversion, e.g. no-till, chisel-till, plough-plant. The no-till system is generally suitable for soils that tend to maintain their structure in regions with sufficient crop residue for mulch and where herbicides are available for weed control. Plough-based systems are usually needed for other soils (with low-activity clays) or in arid and semi-arid climates. The suitability of different tillage systems depends on soil properties, climate characteristics and a range of other factors including socio-economic and anthropological considerations. Soils highly susceptible to erosion should be managed by no-tillage or one of the several ridge-tillage systems.

Residue management

58. Regular and sizeable additions of organic material are essential to maintain an adequate content of soil organic matter and to stimulate activity of soil fauna, such as earthworms and appropriate termite species. This can prevent structural collapse of soils with predominantly low-activity clays. Crop residue mulch is an important ingredient of any improved farming/cropping system. Frequent applications of 4 to 6 tons of residue mulch per ha to the soil surface are beneficial for soil and water conservation, regulating soil moisture and temperature regimes, improving soil structure, enhancing activity of soil fauna, suppressing weed growth and protecting soils from high-intensity rains and from desiccation.

59. While the beneficial effects of mulching are widely recognized, procuring mulch material in sufficient quantity is a serious practical problem. Management of crop residue as a source of mulch is, therefore, closely linked with cropping systems, tillage methods, and planted fallows. A range of cultural practices are available to provide adequate amounts of residue mulch for soil protection and fertility enhancement, e.g. cover crops, conservation tillage, sod seeding, agroforestry. Live mulch, alley cropping, ley farming, planted fallows, use of industrial by-products are some other practices adopted to procure mulch. The suitability of each practice depends on the local biophysical and socio-economic environment.

Crop management

60. A continuous ground cover is necessary to provide a buffer against weather fluctuations and to protect the soil against raindrop impact or high-velocity winds. Timely planting, use of viable seed at optimum rate, improved cultivars and cropping systems, fertilizer use and pest control are all important aspects related to crop management. Benefits of timely planting include buffers against uncertain rains, unfavourable soil temperature regime, pest infestation, and unfavourable market conditions. Planted fallows, both legume and grass covers, are generally more effective in restoring soil fertility and improving the soil's physical properties than natural fallows. Soil organic matter can be increased and soil structure improved over a short period of 2 to 3 years.

61. Mixed cropping, sequential cropping and relay cropping are recommended to create diversity whereby crops of different growth cycles, canopy structures, root systems, and water and nutrient requirements are grown to maximize the use of a limited resource.

62. Agroforestry involves growing trees and woody shrubs in association with annual food crops. The system can also include animals. Alley cropping is a special case of agroforestry in which annual food crops are grown between rows of specially planted woody shrubs or trees. Shrubs are regularly pruned during the cropping season to prevent shading, provide mulch, and reduce water use. If properly managed, prunings from leguminous shrubs can provide 30 to 60 kg N per ha. When planted on the contour, hedges also decrease runoff and soil erosion.

63. Mixed farming can be a stable system for small landholders provided that pastures are not overgrazed, stocking rate is low, and animal waste is applied to the land to replenish soil fertility. Mixed farming with excessive stocking rate and uncontrolled grazing is usually unsuccessful and degradative to soil and environment, as has been the case in the African Sahel.

Water management

64. Water management is crucial to alleviate the adverse effects of recurring drought which seriously curtails crop and animal productivity. For most countries in arid and semi-arid areas, development of irrigation systems is the only option to sustainable agricultural production. For many more, some form of irrigation is necessary to ensure stability of production. The technology for the development and management of irrigation, both large and small-scale, is known. This includes techniques for improvement of on-farm water management, reduction of canal seepage losses, water application (bubbler,

reduction of sprinkler losses), night storage, conjunctive use of ground and surface water, improved use of flood recession waters, skimming wells and water harvesting.

65. Such techniques, properly applied, will considerably reduce irrigation water losses, allow irrigation of more land and substantially increase crop yields. Achieving all this, however, also requires well-functioning institutions, legislative arrangements, economic policies and services.

66. To make irrigation development sustainable, particular attention should be given to the following issues: ensuring the participation of the beneficiaries during all phases of development; assessing the environmental impact of development; ensuring that production output can be marketed and sold at reasonable prices; providing farmers with the necessary support to facilitate the transfer from traditional to intensive irrigated agriculture.

67. Drainage for the control of groundwater levels and soil salinization should be considered an essential part of any new irrigation design. It is also needed to prevent or reduce problems in many older schemes. The technology for both surface and sub-surface drainage is readily available.

68. Various treatment techniques are available that make drainage water and urban waste water suitable for re-use as irrigation water. This helps in providing additional water in areas of water scarcity.

69. While drought is a natural phenomenon in arid and semi-arid climates, its effects and duration are accentuated by human-induced changes in the ecosystem. The effectiveness of rainfall is drastically reduced by anthropogenic soil degradation. Rainfall effectiveness can be enhanced by <u>in situ</u> conservation of water through increasing infiltration and reducing runoff, and decreasing evaporation from the soil surface. Water in the root zone is conserved by conservation tillage, mulch farming, and appropriate cropping systems. Runoff management with safe disposal and storage in small reservoirs can provide supplementary irrigation and drinking water for livestock.

SYSTEMS APPROACH

70. Although the general principles may be the same, technological packages for sustainable management of soil and water resources are site-specific and depend on farming systems, farm size, availability of inputs, and socio-economic factors. Local-specific and on-farm synthesis of packages is needed on the basis of components and sub-systems such as those described above. The agronomic productivity, economic profitability, and ecological compatibility of such packages needs to be assessed through appropriate research on well-defined, representative sites.

71. The results obtained from field experimentation can be validated against predictive models. The latter may be biophysical models, economic productivity models based on linear programming, or statistical models based on systems analysis of empirical data. Field experimentation can bring about a step-by-step improvement by identifying and dealing with each major constraint to crop and animal production. Moderate improvements in traditional farming may be the initial step in a long-term strategy aimed at transforming low-input subsistence farming into science-based commercial agriculture with

high or moderate inputs. Researchable priorities in this approach involve assessment of components or sub-systems for improved traditional farming and commercial agriculture. In addition, specific research priorities include soil and crop management practices that increase the efficiency of water and fertilizer use, and restore eroded and degraded lands.

5. STRATEGIES AND TOOLS

72. National governments are the primary authorities that can develop and carry out strategies for sound, sustainable development and management of their land and water resources.

73. This can be done effectively and well only if the people who use the land are fully informed and involved from the beginning in the formulation and application of the strategies. There must be broad support based on the recognized congruence of individual and society interests, both short- and long-term.

74. Wherever interests transcend national boundaries (e.g. prevention of air and water pollution, safeguarding water supplies from international rivers or minimizing sediment and salt loads in such rivers), governments can act in concert through formal agreements and through tuning their strategies to each other's, regionally or sub-regionally.

75. The support of land users can be built up by:

- **educating** young people and adults on the relationship between human activities and the state of land and water resources, and the environment as a whole;
- **information** to land users on the specific effects of management practices on land and water resources and biota, and on effective and economic practices that are environmentally compatible;
- **persuasion** of land users through legal and policy instruments that assure them a long-term interest in their land; raise the direct costs of environmentally harmful actions; and ensure that benefits from environmentally favourable actions accrue to the land users.

LAND USE PLANNING

76. Nationally, each country will need to base its land use planning on systematic information, comparing the potentials of its land and water resources with the needs of present and future populations.

77. This can be done through a balance-sheet approach using agro-ecological zones information which integrates systematic data on the country's land resources, including climate and its variability, soil and water resources, and estimates their potential for various uses at different input levels. Such agro-ecological zones information was collected, for example, by the Government of Bangladesh with assistance from FAO and UNDP.

78. A long-term land use plan can then be built on this information, taking into account the people's needs, existing and envisaged infrastructure, services and the conservation of the country's biological resources, including their diversity.

79. The overall land use plan will thus be based on the recognition that optimum, wise land use is local-specific, determined by the needs of the people and the different potentials of land and water resources from place to place. Depending on the nature of the climate, soil and water resources, emphasis will need to be placed on different parts of the overall strategy.

80. Where soils are liable to water erosion, an approach based on **soil and water conservation and land rehabilitation** is needed. With scarce water supplies, there should be an integral plan for the **optimum use of water resources**, including re-use of drainage waters for salt-tolerant crops on appropriate land, and the safe disposal of the final effluent. In areas where low-input agriculture is facing low or falling crop yields and decreasing fallow periods because of increasing pressure on the land, the introduction of **integrated plant nutrition systems** (IPNS) including appropriate amounts of mineral fertilizers, will be essential to rehabilitate the land and increase yields. Similar systems can rehabilitate land polluted by excessive amounts of plant nutrients.

PEOPLE'S PARTICIPATION AND LOCAL ACTIVITIES

81. Land and water resources can be degraded by incorrect use or management. Whether or not they are conserved and improved during use depends upon the activities of the individuals using the land and water. Ultimately, the state of the country's natural resources depends upon the combined actions of the farmers, graziers, foresters and other land users who, every day, make decisions and carry out actions affecting them.

82. Governments by themselves therefore cannot assure or bring about sustainable and productive land and water use. They can, however, create the conditions and establish or adapt institutions that encourage farmers to follow sustainable production practices and to participate in the management of irrigation systems through policies, programmes and incentives, provision of infrastructure and services.

83. Integrated land, water and plant nutrient use at local level requires that farmers, graziers and other users be provided with area-specific advice on soil and water conservation, management and development. The adoption of such advice depends on whether it will also bring immediate or short-term economic returns to the user, besides the long-term benefits of sustaining resource potentials. Success will also depend on whether the users have long-term rights to the land and water resources.

84. Examples of such local activities exist. The Government of Lesotho, with assistance from FAO and the Netherlands, has been helping communities to develop and implement their own village conservation and development plans. In Nigeria, farmers are practising successful small-scale irrigation from shallow groundwater, supported by effective extension, credit and marketing facilities through the Bauchi State Agricultural Development Programme. In the Philippines, through the efforts of the National Irrigation Administration, farmers

successfully formed irrigation associations which solved problems in irrigation planning, layout and construction, and operation and maintenance with the active participation of the farmers themselves.

LAND CONSERVATION AND REHABILITATION

85. For efficient conservation and rehabilitation of land resources, inventories need to be made of the land and water resources and of their degradation problems; this information should be stored in readily accessible and usable form; and on this basis, the suitability of the land for different purposes should be evaluated.

86. The underlying causes of land degradation should then be identified by an analysis of land use policies and legislation, land tenure systems, prices and incentives or disincentives, land use practices and customs, preferences and opinions of land users.

87. In consultation with land users, any changes in the framework of laws, policies, tenure systems, prices and incentives can then be designed and introduced to discourage detrimental practices and to encourage and assist the necessary changes in land management and use, or land improvements.

88. The formation of land user groups and associations should be stimulated; these associations can be invited to participate in the identification and adaptation, planning and execution of sustainable land uses or land improvement measures that also provide clear, short-term benefits to the user.

89. The value of conservation and rehabilitation activities needs to be widely publicized and demonstrated, and technical advice and assistance provided to those needing help.

90. To bring about these developments and changes, three kinds of institutions are needed. A high-level advisory body, possibly at inter-ministerial level, should periodically review the situation, develop policies, coordinate actions and monitor progress. Land conservation and rehabilitation services should be established or strengthened to the point that they can provide the needed technical advice and assistance to land users. Facilities are needed, for example in an appropriate institute or university, for training in the technical and social aspects of soil and water conservation, and for development and drafting of appropriate legislation.

OPTIMIZING USE OF WATER RESOURCES

91. In optimizing the use of water resources, irrigation cannot be developed in isolation but must be a part of a wide ranging area development programme. Governments should adopt strategies for irrigation development and management based on the recognition that rainfed and irrigated agriculture are mutually complementary activities. These strategies should promote the profitability of irrigated agriculture, lead to sharing of investment and recurrent costs of governments and farmers, and provide appropriate incentives to farmers to produce more with limited resources.

92. All strategies and programmes need a sound database, including information on land resources and their potential, quantity and quality of water resources, land and water use and production, and socio-economic information. This should be collected, and made available in readily usable form to planners, technicians and farmers.

93. Institutions and infrastructure for provision of credit, input supplies, markets and transportation need to be evaluated and modified as needed to ensure that optimal water use is in fact achieved. This also requires training facilities for extension staff and for farmers, in water management as well as environmental health aspects.

94. Socio-economic analysis as well as environmental impact assessment are prerequisites for water development projects. Integrated environmental monitoring, evaluation and feedback are essential to ensure sustainable development. Emphasis needs to be placed on the management of upper watersheds and implementation of environmental protection measures throughout, from upper watershed to below the irrigation area.

95. Adaptive research, including pilot projects, for example in waterlogged areas, is required to ensure that the technology chosen for development of a given area is technically feasible, environmentally and economically viable, and socially acceptable.

96. Five technical aspects need attention in planning optimum use of water resources: use efficiency, waterlogging and salinity, water quality management, small-scale water programmes and water scarcity.

97. Raising the **water use efficiency** requires improved water management in the main system as well as on the farm. This requires the introduction of appropriate water pricing policies. Wherever feasible, irrigation facilities and management systems must be adjusted to permit water supplies to crops when they are needed. Farmers should participate in all phases of development and management. This requires training of farmers, adequate extension services and strong water users' associations.

98. **Waterlogging and salinity** should be prevented or corrected by a two-pronged approach: improved system design and on-farm water management practices to reduce the sources of excess water, complemented by drainage systems, managed and maintained with farmers' involvement. Re-use of drainage water on appropriate crops and suitable soils, conjunctive use of surface and groundwater, and safe disposal of final drainage effluent will further counteract waterlogging and salinity.

99. **Water quality monitoring and management** systems are needed to ensure acceptable water quality for agriculture as well as for subsequent uses.

100. **Small-scale water programmes** can fulfil many local water needs and can meet part of national food requirements, generate employment, promote equity, enhance community participation and help to slow migration to urban areas. National policies should be formulated to support small-scale water programmes. These should be based on sound technical advice and support, and on good collaboration between local government, NGOs and local communities.

101. Management of **scarce water resources** is vital to arid and semi-arid countries and other drought-prone areas. These require integrated and long-term strategies for land and water use designed to cope with drought situations, including conservation and appropriate utilization of groundwater sources.

SUSTAINABLE DEVELOPMENT OF SOIL PRODUCTIVITY

102. Soil productivity can be improved and maintained by integrated plant nutrition systems (IPNS), which address two important problems: the low and decreasing crop yields caused by plant nutrient depletion in many soils and inefficient fertilizer use in the developing world; and the less extensive but similarly serious problem of pollution by excessive and inappropriate plant nutrient applications in developed countries and locally in developing countries.

103. The basic concept underlying IPNS is the maintenance or adjustment of soil fertility to an optimum level for sustaining the desired crop productivity through optimizing the benefits from all possible sources of plant nutrients in an integrated manner. The appropriate combination of mineral fertilizers, organic manures, crop residues, compost or N-fixing crops varies with the system of land use and ecological, social and economic conditions.

104. In many cases, minimizing external inputs through optimal combinations of plant nutrient sources available within the farm will be one of the objectives. Increased efficiency as well as reduction of off-farm inputs contribute to environmental conservation and decrease or eliminate pollution of soils and groundwater.

105. Application of IPNS on a large scale requires some adaptive research, demonstration programmes backed by training in good management practices, and a policy improvement and infrastructure stimulating the efficient use of both internal and off-farm inputs.

106. Depending on the situation in each country, this may imply changes in policy or legislation, prices, incentives or taxes, as well as institutions.

107. A strategy or action plan for the sustainable development of soil productivity through IPNS would involve the mobilization of advisory services as well as of land users associations. It may also require technical assistance, aid-in-kind and other supply options, revolving funds and national production of mineral fertilizers.

INTERNATIONAL COOPERATION

108. **Regionally,** priority should be given to the establishment of regional networks and institutions for information exchange and advanced training. The institutions should document and disseminate, with international support, examples of successful and sustainable soil and water management practices. Governments should intensify efforts to formulate agreements for the allocation and protection of interstate and international waters as an important requirement for sustainable agriculture. Such regional cooperation is exemplified by the Mekong Committee, based in Bangkok, Thailand, which coordinates the development of the basin's resources on the basis of equitable sharing between states. The Committee has been instrumental in the collection of basin-wide data, the exchange of technologies among member states and the implementation of development projects.

109. **Globally,** there is a need for coordination of international action: Long-term financing can be assured if national governments, NGOs, technical assistance agencies and financing institutions work together to formulate policies and elaborate programmes.

REFERENCES

Brown, L.R. (1981). World population growth, soil erosion and food security. Science, 214:995-1002

Beek, K.J., W.A. Blokhuis, P.M. Driessen, N. Van Breemen, R. Brinkman, and L.J. Pons (1980). Problem soils: their reclamation and management. ILRI Publ. No. 27, pp. 47-72. ILRI, Wageningen, Netherlands.

Buringh, P., H.D.J. Van Heemst and G.J. Staring (1976). Computations of the absolute maximum food production of the world. Agric. Univ., Wageningen, Netherlands.

Buringh, P. (1989). "Availability of agricultural land for crop and livestock production". In D. Pimentel and C.W. Hall (eds) Food and natural resources, Academic Press, 70-85.

Dudal, R. (1982). Land degradation in a world perspective. J. Soil and Water Conserv. 37:245-247.

Duttweiler, D.W. and H.P. Nicholson (1983). "Environmental problems and issues of agricultural non-point source pollutions." In F.W. Schaller and G.W. Bailey (eds) Agricultural management and water quality, Ames, Iowa: Iowa State Univ. Press, 3-16.

FAO (1984). Land, food and people. FAO, Rome, Italy.

Griggs, D. (1985). The world food problem: 1950-1980. Blackwell, Oxford.

Hall, C.W. (1989). "Mechanization and food availability". In D. Pimentel and C.W. Hall (eds), op cit, 262-275

Lal, R. (1990). Managing soil carbon in tropical agro-ecosystems. EPA Workshop on Sequestering Carbon in Soils. Corvallis, Oregon, 26-28 Feb. 1990.

Le Houerou, H.N. (1977a). The scapegoat. Ceres 10:14-18.

Le Houerou, H.N. (1977b). "The nature and causes of desertification". In M.H. Glantz (ed) Desertification, pp. 17-38, Westview Press, Boulder, Colorado.

Lu, M., J. Ysheng and S. Chenyueng (1982). Typical analysis of rural energy consumption in China. Nongya Jingji Luenchung 4:216-223

Mabbutt, J.A. (1978). The impact of desertification as revealed by mapping. Environ. Conserv. 5:45-56.

Perrens, S.J. (1986). "Conversion of forest land to annual crops: Australian experience". In Land use, watersheds and planning in the Asia-Pacific Region, pp.112-137, RAPA Rep. 1986/3, FAO Regional Office for Asia and the Pacific, Bangkok.

Pimentel, D. (1989). Ecological systems, natural resources, and food supplies. In D. Pimentel and C.W. Hall (eds) op cit. 2-31.

Revelle, R. (1976). The resources available for agriculture. Scientific American, 235:64-168

Suarez de Castro, G.K. and G.A. Rodriquez (1958). Movimiento del agua en el suelo. Estudio en Pisimetros nonoliticos. Bol. Tec. Fed. Nac. Cafeteros Colomb. No. 2.

UNEP (1982). World soil policy, Nairobi.

UNEP (1984). General assessment of progress in the implementation of the Plan of Action to Combat Desertification: 1978-84. Mimeo. UNEP Governing Council, 12th Session, Nairobi.