1 Learning from Bright Spots to Enhance Food Security and to Combat Degradation of Water and Land Resources[1]

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Introduction

One of humanity's great achievements has been to produce enough food to feed the largest global population ever. But a marked failure has been to ensure food security for everyone. An estimated 800 million people do not have access to sufficient food supplies, mostly in South Asia and sub-Saharan Africa. Areas with the greatest water loss and land degradation correspond closely with areas of the highest rural poverty and malnutrition, and food and environmental insecurity. Loss and degradation of water and land for agriculture are not universal, but are widespread and accelerating, particularly in developing countries.

Major concerns related to degradation are: (i) loss of water for agriculture and reallocation to cities and industries; (ii) reduction in land quality in many different ways, leading to reduced food supplies, lower agricultural incomes, increased costs to farmers and consumers, and deterioration of water catchment functions; (iii) reduction in water quality due to pollution, water-borne diseases and disease vectors; and (iv) loss of farmland through conversion to non-agricultural purposes. This chapter analyses processes in relation to four major zones: headwaters, plains, urban areas and coastal areas, which cover five ecosystems. The processes and their management are quite different among these zones and systems.

Fortunately, there are also 'bright spots', where degradation has been reversed or mitigated and household food and environmental security have been achieved. Lessons from such successful experiences are briefly mentioned, and it is suggested that an understanding of their emergence can help in the creation of more bright spots. With respect to research, six key areas for further research are identified.

Status of the World's Ecosystems and Hydronomic Zones

The world's land and water resources provide goods such as food crops, fish, livestock, and timber and non-timber products. They also provide ecological services such as purification of air and water, maintenance of biological diversity, and decomposition and recycling of nutrients (WRI, 2000). Despite the importance of these resources, land and water ecosystems are being degraded at an alarming rate. This section provides a brief global overview of the status of land and water in three terrestrial ecosystems – agriculture, forests and grasslands – and two aquatic ecosystems – freshwater systems and coastal and marine systems. The consequences of degradation processes in these resources and the possibilities for management and intervention depend in large measure on which hydronomic zone the ecosystem is located in: upper catchments, plains, peri-urban areas or coastal zones.

Agricultural ecosystems

Agricultural ecosystems (agroecosystems) refer to natural landscapes that have been modified by humans for agriculture. These ecosystems cover about 25% of the world's total land area, excluding Greenland and Antarctica. Together with mangrove forest and riparian lands, they account for 90% of all animal and plant protein and almost 99% of the calories that people consume (FAO, 2001a; WRI, 2000). Around 40% of the world's population lives in agroecosystems with irrigated and mixed irrigated/rainfed agriculture, even though they occupy only 15% of the agricultural extent. Arid and semi-arid agroecosystems, on the other hand, comprise around 30% of the agricultural extent, but they contain only 13% of the population (Wood *et al.*, 2000; FAO, 2001a). Globally, about 800 million people are poor (and probably, therefore, hence food insecure), 300 million of whom dwell in the semi-arid tropics (Ryan and Spencer, 2001).

Expansion of cropping in recent years means that over 50% of the major river basins in South Asia, as in Europe, are now under agricultural cover; over 30% of the basin area is under agricultural cover in South America, North Africa, and South-east Asia, as in the United States and Australia. But two-thirds of agroecosystems have been degraded over the last 50 years (WRI, 2000). Unsustainable methods of land use are diminishing agroecosystems' capacity for agricultural production. The main causes of this ecosystem's degradation are: (i) increased demand for food for a rapidly growing population, resulting in agricultural intensification and shortened fallow periods; (ii) inappropriate agricultural policies such as ill-designed subsidies for water, fertilizers, and other agrochemicals; (iii) the use of agricultural machinery and agronomic practices that are unsuited to local conditions; (iv) concentrations of livestock that lead to overgrazing and water pollution; (v) loss of natural vegetation, which serves as buffers, waterway filters, dry-season fodder reserves, and habitat; and (vi) poorly constructed infrastructure, which leads to land fragmentation and erosion and disrupts hydrological systems. In addition, (vii) the inadequacy of legal frameworks for managing land and water in many countries and the shortage of implementing arrangements provide insufficient guidance for sustainable stewardship to allow for food and environmental security.

Forest ecosystems

Forests cover approximately 33% of the world's land area, excluding Greenland and Antarctica (FAO, 2001b). Recent estimates of forest coverage indicate that up to 50% of the world's original forest cover has been cleared already, and deforestation continues. Deforestation of tropical forests alone is estimated at more than 130,000 ha per annum (WRI, 2000). The main causes of this ecosystem's degradation are: (i) growing demands for forest products; (ii) policy failures such as undervaluation of timber stocks, which provide economic incentives for inefficient and wasteful logging practices; (iii) agricultural subsidies that favour the conversion of forests for large-scale agriculture; and (iv) fragmented and weak institutional frameworks to support the conservation and sustainable use of forests.

The impacts of deforestation include land and water degradation, displacement of people, especially indigenous people who depend directly on the forest for their survival, and biodiversity losses. Deforestation has also caused significant adverse hydrological changes to some of the world's major watersheds. Forest degradation, including the setting of fires, accounts for 20% of the world's annual carbon emission (WRI, 2000).

Grassland ecosystems

Grasslands cover approximately 52.5 million km^2 or 41% of the world's land area, excluding Antarctica and Greenland. Humans have modified grasslands significantly, in part by converting them to farming and urban development. Only 9% of grasslands in North America and 21% in South America are still intact, and more than 50% of the original grasslands of Asia, Africa and Australia have been lost (WRI, 2000). The main threats to the world's remaining grasslands are: (i) urbanization and conversion to cropland; (ii) inappropriate use of fire to manage grasslands; (iii) excessive grazing pressure from livestock; and (iv) the poor management of communal lands.

The impacts of grassland degradation include the loss of biodiversity due to the conversion or fragmentation of habitats; soil degradation, particularly erosion due to the loss of vegetation cover; and soil compaction from high livestock-stocking densities. Finally, the burning of grasslands is a major contributor to carbon emissions. In Africa, for example, grassland burns account for some 40% of carbon emissions from biomass burning on that continent (WRI, 2000).

Freshwater ecosystems

The freshwater ecosystem includes two interconnected components: surface and groundwater. Surface freshwater systems – rivers, lakes and wetlands – occupy 1% of the earth's surface area. Surface freshwater ecosystems face three major threats: (i) fragmentation of rivers by structures such as dams, diversions and canals. It is estimated that 60% of the world's basins are already strongly or moderately affected by fragmented or altered flows (WRI, 2003). Plans continue afoot for more such construction, and in China, India and the Middle East (Iraq, Iran, Turkey) many are presently underway; (ii) excessive water withdrawals from rivers and from groundwater, leading to river desiccation; and (iii) pollution of surface water by agricultural chemicals (including fertilizers, pesticides and herbicides), animal waste (especially from intensive livestock systems), and industrial chemicals. Groundwater is an important source of water for about 1.5–2 billion people. Some of the largest cities in the world, including Dhaka, Jakarta, Lima and Mexico City, depend almost entirely on groundwater for drinking water (Sampat, 2001). Groundwater depletion occurs when water withdrawals exceed natural recharge. In the most pump-intensive areas of India and China, water tables are falling at a rate of 1–3 m/year. Groundwater systems face two major threats: (i) over-utilization, resulting in increased extraction costs and, ultimately, the danger of degrading aquifer capacity; and (ii) pollution by agricultural and industrial chemicals.

Coastal and marine ecosystems

Some 2.2 billion people, nearly 40% of the world's population, live within 100 km of a coastline (WRI, 2000). Human pressures include harvesting of natural resources, such as fish and mangrove forests; infrastructural development; and industrial, agricultural and household pollution. Coastal habitats or resources that are under severe threat from human activities include mangrove forests, coral reefs and fisheries. The main threats to mangrove forests are excessive harvesting for fuelwood and timber, conversion to shrimp aquaculture, and the development of urban and other types of infrastructure. The main threats to coral reefs are land reclamation, coastal development and coral mining, but also siltation and pollution.

Fish are an important source of animal protein for people. They provide about one-sixth of the human intake of animal protein worldwide, and are the primary source of protein for about 1 billion people in developing countries. In Asia, it is far in excess of livestock-derived protein products. Fisheries are under pressure from overfishing, which occurs because of excess harvesting capacity in the world's fishing industry. According to one estimate, the level of fish harvesting exceeds sustainable levels by 30–40% (WRI, 2000).

Hydronomic Zones

To improve management opportunities, this chapter develops its analysis of ecosystems from a geographical perspective (Penning de Vries *et al.*, 2003). These 'hydronomic zones' are: 'headwaters (or upper catchments)', 'plains', 'cities' and 'coastal areas'. The term 'hydronomic zone' expresses the relationships between ecosystems and water, and hence needs an integrated picture for management. A schematic overview of the zones is shown in Fig. 1.1. Highlights of the driving factors and their impacts per zone are presented below. Note also that these large zones are interconnected and cannot be considered in isolation: water flows through the zones, and there is movement of plant nutrients (in feed and food) and soil particles (as pollutants and sediment); there are connections through infrastructure (roads, channels, housing, dams, airports, recreational facilities); and there is movement of people.

Upper catchments

Degradation drivers

Some headwater areas are sparsely populated and are often largely forested. In others, human settlement may have resulted in fairly intensive permanent cultivation. In sparsely populated areas, degradation often starts with shifting cultivation (slash and burn), and in a few cases as logging operations. Since the late 1950s, the

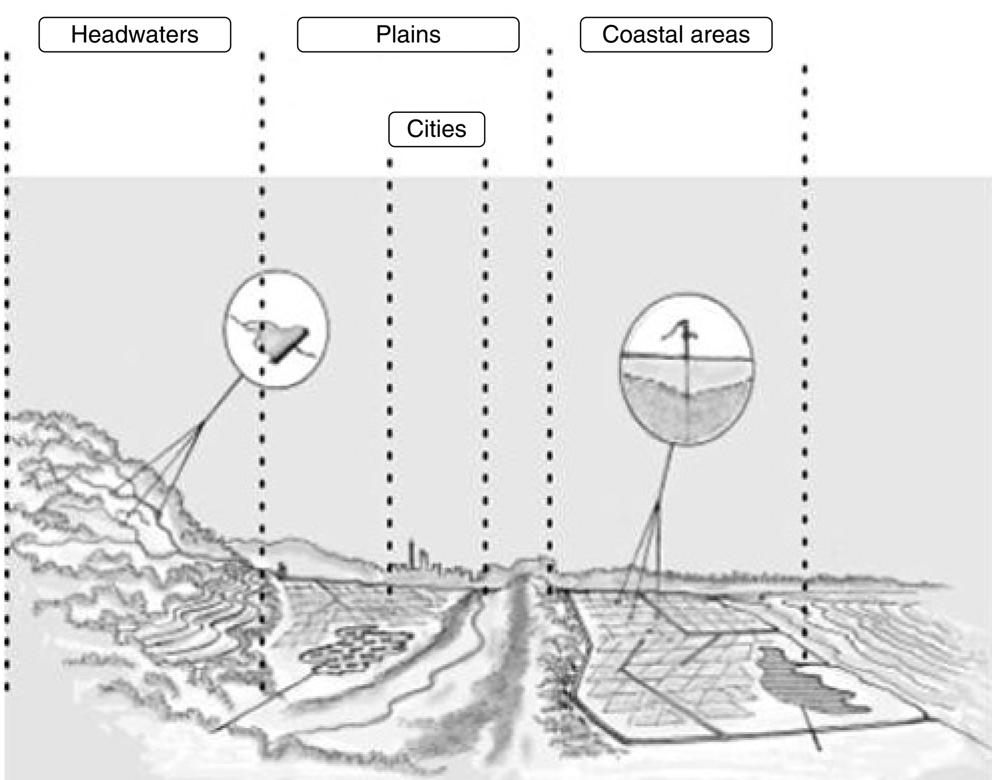

Fig. 1.1. A graphical representation of the hydronomic zones (Molden *et al.*, 2001).

number of people has expanded due to population growth, migration and relocation, and due to the absence of effective laws or control measures. In more populated headwaters, a major degradation driver is that yields are not growing at a rate commensurate with population growth and increasing food needs. Riparian and other land-protecting natural vegetation may be removed to provide land; intensive crops with several stages of crop and livestock integration may replace extensive grazing systems. (Erroneously, often only the farmers are accused of causing degradation, but, in many parts of the world, mining operations, the construction of infrastructure and natural geological processes are the most important sources of erosion, sedimentation and pollution.)

Land and water degradation processes

Key processes are erosion and sedimentation, nutrient depletion, water pollution, de-vegetation and irregular stream flow.

Degradation hotspots

The foothills of the Himalayas, sloping areas in southern China and South-east Asia, the East African Highlands, sub-humid Central American hillsides and semi-arid Andean valleys (Scherr and Yadav, 1996). In vast areas, all topsoil has been washed away. In others, the productive potential of the lands has been degraded significantly.

Effects on food security

Land and water degradation in headwaters can seriously reduce household food security through reduced income and food production. This is a two-way process: a less secure food production system often leads to more degrading farming practices, or the so-called 'downward spiral'. Due to generally low yields and high transport costs, 'headwaters' do not contribute much to global food security. They may, however, play a very important role in national urban food supplies and for rural, non-farm populations.

Plains (lowland plains)

Degradation drivers

There are different types of production systems in lowland plains: intensive systems on irrigated and high-quality lands; low-productivity cropping systems in very dry or very wet areas; and extensive livestock systems. The principal degradation driver in irrigated and intensive rainfed agriculture is intensification, through increased and often inappropriate application of fertilizers, water and pesticides. Over- and underuse of water, fertilizers and pesticides cause the problems. Intensification requires extra water, from either surface irrigation or groundwater, and overuse or misappropriation leads to problems. Intensive livestock production produces high levels of potentially polluting waste.

Land and water degradation processes

From the perspective of food security, the most important forms of land and water degradation are groundwater depletion, salinization, nutrient depletion, water pollution, de-vegetation and wind erosion. These processes play out in very different ways under different soil, climate and management circumstances.

Degradation hotspots

Hotspots of groundwater depletion are common in significant areas of the Indian subcontinent and north-east China, where the number of farmers using groundwater has increased significantly but pumping is rarely regulated. Salinization is a major problem particularly in irrigated areas in west, central and South Asia. Hotspots of nutrient depletion include much of Africa (Drechsel *et al.*, 2001), where very old and weathered soils have lower natural reserves of fertility; rainfed areas of west, South and South-east Asia; and rainfed areas in Central America, where strong leaching causes chemical degradation.

Consequences for food security

The plains are the geographic zone where most food and feed production takes place, particularly in Asia, North and South America, and Australia. Irrigated systems are very important from the point of view of food production ('food baskets'), even though 60–70% of all food is produced in rainfed systems in the plains. Degradation of land and reduced water availability lower the ultimate potential of global food production, but do not yet threaten global food security. The great use of water for irrigation in this zone often comes at the expense of water for nature.

Urban and peri-urban areas

Degradation driver

A major driving force of degradation in this hydronomic zone is high resource-use intensities and lack of recycling. As cities grow and inhabitants become more affluent, this driver will become much stronger.

Degradation processes

Changes in hydrology, subsidence, water and soil pollution, and non-agricultural uses of land and water.

Degradation hotspot

Key hotspots are large and very large cities with little water in the form of rain or rivers and with few facilities to handle waste and wastewater. Hotspots probably include all major urban conglomerations in developing countries: Mumbai, Lagos, Dhaka, Sao Paulo, Karachi, Mexico City, Jakarta, Calcutta, Delhi, Manila, Buenos Aires, Cairo, Istanbul, Beijing, Rio de Janeiro, Hyderabad and Bangkok. In the peri-urban areas, concentrated livestock production poses problems of waste disposal, and surface and groundwater pollution. The strongest effects are in the water immediately downstream of and under the city, and in the land on which it is built and that which surrounds it.

Consequences for food security

At a national scale, the expansion of megacities will result in less land for agricultural enterprises. At the household scale, urban and peri-urban agriculture often provide good incomes and increase household food security. The use of wastewater and compost on crops assists with nutrient recycling and stimulates income generation, but in many cases may lead to irreversible contamination of soils, which limits the productive capacity of the areas affected. Dirty waterways in the city reduce livelihood quality, particularly for the urban poor. As health risks increase, it is the poorer sectors of the economy that are most vulnerable and, as a consequence, food security is reduced. Due to the use of wastewater and the reliance on pesticides, production and consumption of vegetables in urban and peri-urban areas often becomes a health hazard.

Coastal Systems

Degradation drivers

High population densities, supplemented in some areas by a significant tourist population, put heavy pressure on coastal and marine environments. Coastal areas are at the receiving end of upstream land and water degradation processes. Shoreline modification has altered sea currents and sediment delivery mechanisms. Sea level rise caused by climate change will exacerbate pressure on coastal ecosystems.

Degradation processes

The main processes here are seawater intrusion, desiccation of rivers, pollution and sedimentation in coastal water, and the reclamation of wetlands.

Hotspots

Degradation due to sedimentation and water pollution occurs in most tropical coastal areas and river deltas, particularly in South-east and eastern Asia. Seawater intrusion is prevalent in the coastal areas of Egypt, China, India, Vietnam and Turkey.

Impacts on food security

Degradation has a negative effect on those who rely on fishing for their livelihoods (catches decline, fish become smaller and cheaper).

Underlying Problems in Water and Land Resource Degradation

Lack of political awareness

Lack of awareness at political levels is one underlying feature of resource degradation. Until recently, policy makers and policy analysts have not considered land and water loss and degradation to be important threats to food security, with notable exceptions, however (See Scherr, 1999a,b; 2001). It has been widely assumed that 'land' is a stable production factor and less important than other factors in determining agricultural productivity. The need for (improved) water management in relation to irrigation has been well recognized (Vermillion *et al.*, 2000), but improving water use on non-irrigated land has not been much of an issue. In addition, the degradation of agroecological systems is perceived as being a slow process that can always be reversed with adequate inputs. Ecosystems are, however, resilient only up to a certain threshold, and collapse when stressed beyond this level. One major reason why slow degradation received little attention is that it invisibly lowers the capacity for production, while investments allow actual production to go up. When the rising production hits the falling ceiling, however, consequences of degradation suddenly appear and the process is hard to stop (Fig. 1.2).

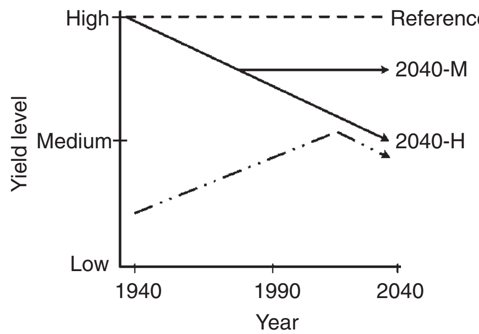

Fig. 1.2. Hypothetical example of how maximum yield level of crops (obtained in optimal biophysical conditions and used here as the reference yield level, per unit land or per unit water) becomes reduced due to degradation. Two scenarios are shown: continuation of the current rate of degradation (labelled 2040-H), and a rate half as much (labelled 2040-M). The actual level of agricultural production (dot–dash line) rises in time due to intensification, until it approaches the potential level, after which it must also decrease (after Penning de Vries, 1999).

Degradation of water and of land occurs in parallel

The degradation of both land and water leads to fewer ecosystem services, in particular a reduced capacity for food production and income generation. Both are the result of poor management. For instance, in an analysis of the Pakistan Punjab, Ali and Byerlee (2001) found that:

> Continuous and widespread resource degradation, as measured by soil and water quality variables, had a significant negative effect on productivity. Degradation of agroecosystem health was related in part to modern technologies, such as fertilizer and tube well water, offsetting a substantial part of their contribution to productivity.

Globally, poorly situated or mismanaged irrigation has led to salinization on about 20% of irrigated land, and about US$11 billion in reduced productivity. Intensification in high external input agroecosystems has resulted in the leaching of mineral fertilizers (especially nitrogen), pesticides and animal-manure residues into watercourses, due to poor management or inadequate technologies (Barbier, 1998). On sloping lands with lower-quality soils, intensification has tended to increase soil erosion as well as the effects of sediment on aquatic systems, hydraulic structures and water usage (Wood *et al.*, 2000; Valentin, 2004).

Increasing water withdrawals from river systems

From 1900 to 1995, global withdrawals from river systems for human use have increased from 600 to 3800 km^3/year (Shiklomanov, 1999). Annual agricultural withdrawals are now in the order of 70% of the total, and in many developing countries irrigation withdrawals are over 90% of all water withdrawn for human use. From another perspective, of the 100,000 km^3/year reaching the earth's surface, only 40% reaches a river or groundwater storage. Of this amount, 3800 km^3 is now diverted from its natural courses (based on Shiklomanov, 1999). The other 96% of this renewable resource is 'consumed' in the five ecosystems, including rainfed agriculture. Of the total evaporation from land surfaces, 15–20% results from rainfed agriculture and 5% from irrigated; the 17% of global cropland that is irrigated produces 30–40% of the world's crops. The share of cropland that is irrigated increased by 72% between 1966 and 1996 (not including the growing use of small-scale irrigation systems that provide supplementary water to mainly rainfed cropping systems), greatly contributing to global food security. The growing use of water for food production (Fig. 1.3), however, removes more and more water from natural uses, fuelling depletion, pollution and competition for the resource. In many basins of the world, such as those of the Murray–Darling, the Colorado, the

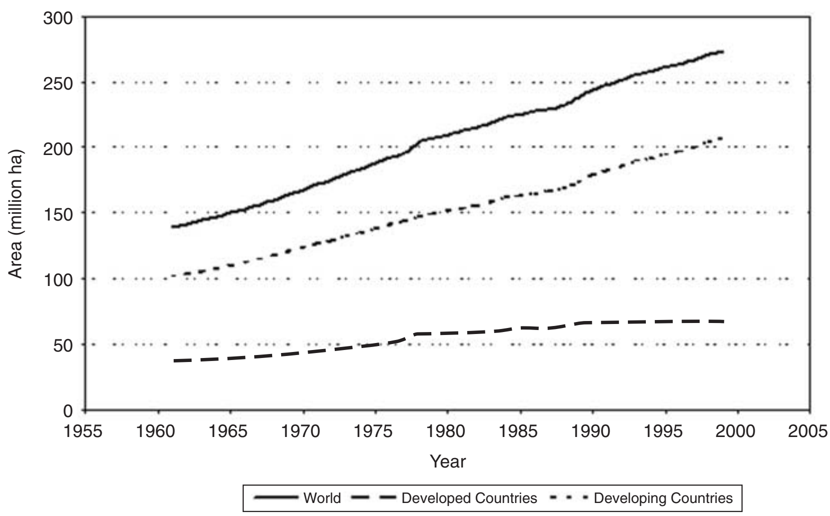

Fig. 1.3. Development of the net irrigated area in the world, since 1960 (Source: FAOSTAT, 2000).

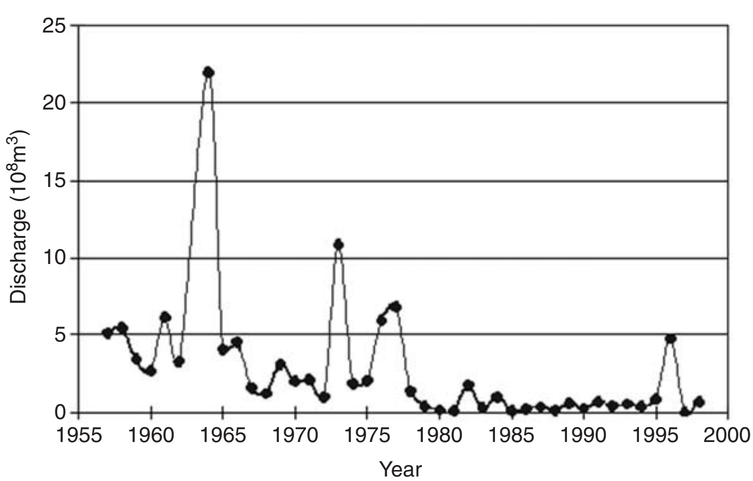

Fig. 1.4. Up to the 1960s, Fuyang River was an important shipping channel for PR China's Hebei Province. But from the 1990s onwards, the river had over 300 dry days annually. The outflow dramatically decreased from the late 1970s, with some 100 million m^3/annum, to zero outflow in 1990 (Source: Wang and Huang, 2001).

Indus, the Yellow River and the Fuyang, there is simply no more water for additional irrigation uses (Fig. 1.4). In the search for additional resources, farmers tap into groundwater and wastewater for irrigation. In many breadbasket areas, groundwater use has reached unsustainable levels. Competition for water between agriculture and urban interests is sharp.

How we resolve the world water crisis very much depends on how well water is managed in agriculture. Increasing the productivity of water in agriculture holds a key to solving water depletion and pollution problems, but productivity per unit of water in many regions remains far below potential. Increasing the productivity of water will mean less water required in agriculture, easing pressures on strained water resources.

It is evident that degradation is widespread and that it often lowers the water-use efficiency. Wood *et al.* (2000) indicate that 40% of agricultural land in the world is moderately degraded and a further 9% strongly degraded, reducing global crop yield by 13%. As an order of magnitude, this points at a reduction in water-use efficiency of least 13% (compared with what it could have been now).

Strip-mining of land resources

Degradation has been taking place extensively for as long as agriculture has been practised (Ponting, 1991). Yet it is hard to quantify it because of the slow and very heterogeneous nature of the process. Indeed, some argue that degradation may be much exaggerated (Mazzucato and Niemeijer, 2000). One informed estimate of the global extent of degradation is that by 1960 as much land in the world was degraded as was in actual production (Rozanov *et al.*, 1990), particularly in Europe, Asia and Africa. Many studies indicate that, since then, degradation has continued at an accelerated pace (Bridges *et al.*, 2001). This reduces the resource base available for agriculture. It is probable, therefore, that actual yields will meet the declining local yield ceiling in more and more places. While genetic crop modification can possibly delay this time by increasing the efficiency of extracting water and nutrients, the fact remains that all crops need these resources to grow.

We have made a crude attempt to extrapolate the extent of degraded areas from the 1960s with more recent data, and to compare the calculated extent of degradation with the total of land suitable for cultivation. In this chapter, results are shown (Fig. 1.5) for two regions: Latin and Central America (LAC) and the Middle East and North Africa (MENA, regions as defined by the World Bank). The figure presents land that was in principle suitable for agriculture in three fractions: a fraction already degraded, a fraction in use and a fraction in reserve. The starting point for these calculations was to estimate the total area of land that could have been made suitable for modern agriculture (not too stony or shallow, gentle slopes, fair climate, etc.) and before anthropogenic land degradation occurred. The area includes land already cultivated and much land that is currently forested. Data were taken from the study on global carrying capacity under contrasting views of societal values towards natural resource use (WRR, 1995). This maximum area is shown as 100% and does not change over time. The total area of degraded land in Fig. 1.5 is based on Rozanov *et al.* (1990) plus an estimate of the growth rate of degraded areas, extracted from GLASOD (Oldeman *et al.*, 1990) and other sources (Penning de Vries, 1999). The area of land in use for agriculture was taken from FAO databases (FAOSTAT, 2000). Note that the degradation of ‘land’ in this context implies loss of quantity or quality of soil and/or water; and also that ‘regions’ as distinguished here are the sum of several countries that differ enormously in land resources and populations, so that conclusions about specific countries cannot be drawn from this work.

At the global level, this analysis provides important insights. First of all, by reading the figure as a sequence of time-slices, it is possible to imagine a process of opening up new areas of land, farming these for some time, and then leaving degraded land behind. Such a progress is not unlike ‘strip-mining’. It is important to realize that human beings are actually slowly destroying the resource base for agriculture, because while our land resources are large, they are also limited. Thus, in this process of land cultivation the net expansion of agricultural area of around 2%/year is actually an expansion of 3%/year, with an increase in the extent

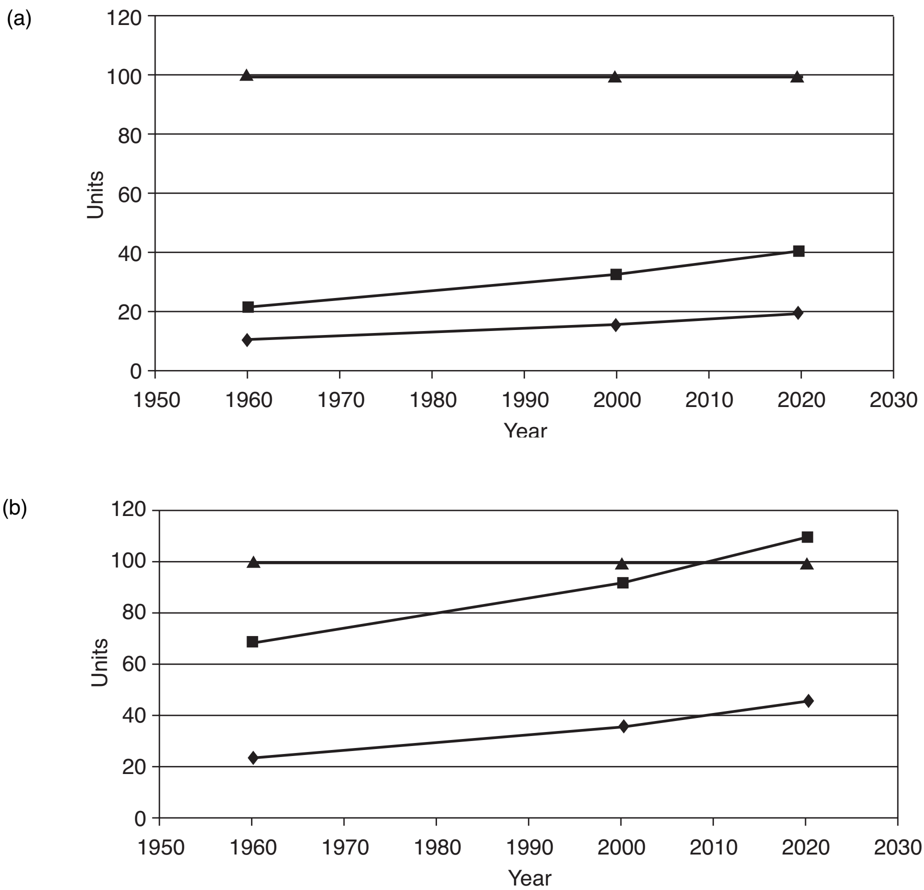

Fig. 1.5 Declining land resources in Latin and Central America (LAC) and in the Middle East and North Africa (MENA). Figure 1.5a reflects the dynamic situation of land resources in Latin America; Fig. 1.5b in the Middle East and North Africa. In both figures, the upper line (triangles) represents the area of land in principle suited for agriculture in prehistoric times. Assuming that climate change has not modified the extent of this area, the line shows a constant value (100%). That part of the graph below the lower line (diamonds) represents the area of land fully degraded and no longer of agricultural value. The part of the graph between the lower and the middle line (squares) represents the area in use by farmers. The part of the graph between the upper two lines represents the area still available for agriculture. In MENA, all land suitable for agriculture is in use, plus some area that is actually unsuitable for this purpose.

of degraded land by 1%/year. Second, Fig. 1.5a and b shows a huge difference between the two regions: in MENA, nearly all land that is suitable for sustainable agriculture is already being used fully. To meet growing food demands, there is no alternative but to intensify cultivation of suitable soils. Comparing the approximate extent of suitable land to used land indicates that already significant areas of land unsuitable for cultivation (too shallow, saline, etc.) are actually cultivated to extract a meagre income (e.g. overuse evident in 2020 in MENA). This is not sustainable ecologically, socially or economically, and it may not be possible to achieve household food security through agriculture in these areas. In contrast, LAC is far from using all its natural resources for agriculture, mainly because of large forested areas. We do know, however, that in some countries and upper catchments, the same situation exists as presented for MENA, as reported before under 'hotspots'.

Food Insecurity and Degradation

The geography of rural poverty

Food insecurity is closely associated with poverty. Approximately 1.2 billion people in the developing world are absolutely poor, with only a dollar a day or less per person to meet food, shelter and other basic needs. The World Development Indicator 'Poverty' (World Bank, 2001) shows the proportions of total populations below national and international poverty lines. Most of the poor inhabit rural areas, but their numbers in urban areas are rapidly increasing.

The total rural population in the developing world in the mid-1990s was about 2.7 billion, of whom about one-third lived on 'favoured' land, defined as rainfed or irrigated cropland in areas that are fertile, well-drained, topographically even and with adequate rainfall. Such land has a relatively low risk of degradation. The other two-thirds of the rural population either lived on 'marginal' agricultural land, defined as land currently used for agriculture, agroforestry and grazing that has serious production constraints, or dwelt in forests and woodlands or on arid land. These are all areas especially prone to degradation without careful management (Table 1.1). We approximated rural poverty in the two areas by applying national percentages to the respective areas. The results show that nearly 630 million rural poor live on marginal agricultural, forested and arid land, and 320 million live on favoured land. This is presumably an underestimate of the poor living on marginal land as the rate of poverty in those areas is likely to be higher than the national average.

As many as 1.8 billion people live in areas with some noticeable land and water degradation, which reduces the quality of livelihoods and household food security. There is a pressing need for better information at local, national and global scales on these relationships. None the less, it appears that areas with the greatest potential for land and water degradation – those with highly weathered soils, inadequate or excess rainfall, and high temperatures – do correspond closely with areas of highest rural poverty.

It is logical to assume that land and water resources that are poor, or rapidly degrading, contribute to poverty and food insecurity. There are strong indications that the consequences of degradation for food security at the household level already affect many people significantly (e.g. ADB, 1997; Bridges *et al.*, 2001; Scherr, 2001). Land and water degradation may impact food security in four ways: by reducing household consumption, national food supplies, economic growth and natural capital.

Reducing consumption of rural households by:

- Reducing subsistence food supplies.
- Reducing food purchases due to higher food prices.
- Reducing household incomes, by increasing the need for purchased farm inputs, increasing the share of purchased food and increasing food prices.

Table 1.1. Geographic distribution of the rural poor (in millions).

Region (no. countries)	Sub-Saharan Africa (40)	Asia (20)	Central and South America (26)	West Asia and North Africa (40)	Total (106)
Total population	530	2840	430	345	4145
Total rural population	375	2044	117	156	2692
Rural population on favoured land	101	755	40	37	933
Rural population on marginal land	274	1289	77	119	1759
Rural poor on favoured land	65	219	24	11	319
Rural poor on marginal land	175	374	47	35	631
Average rural poverty (%)	64	29	61	29	36

(Source: Scherr 1999a, based on Nelson *et al.*, 1997, Table 2.4.)

- Reducing agricultural employment.
- Negative health effects due to reduced water quality or food consumption.
- Reducing the supply of domestic water.
- Reducing the use of irrigation water, particularly for the poor.
- Increasingly difficult access to water.

Reducing global and national food supplies

- Very rough estimates suggest that, globally, the cumulative productivity losses from 1945 to 1990 were 11–13% for cropland and 4–9% for pasture, as a result of land and water degradation.
- These cumulative cropland productivity losses are 45–365% higher in Africa, Asia and Latin America than in Europe and North America (Scherr, 2001).
- In Central America, 75% of agricultural land has been classified as degraded.
- For Africa, existing data suggest widespread loss of productive potential, due to the intensive use of soil types highly sensitive to erosion and nutrient depletion, or inherently low in nutrients and organic matter.
- Studies in Central America show high production losses due to erosion (Scherr, 2001).

Reducing economic growth by:

- Economic multiplier effects of reduced farm household expenditures and agro-industries.
- Higher food prices.
- Increased out-migration from degraded or water-scarce areas, thereby depressing urban wages.
- Reduced agricultural gross domestic product: 1–5%/year in a majority of studies on soil erosion, and over 5%/year in half of the studies on nutrient depletion.
- The discounted future stream of losses from soil degradation raises the cost equivalent to 35–44% of the agricultural GDP in studies in Ethiopia and Java (Scherr, 1999a).
- In Latin America, high soil nutrient depletion rates in most cropping systems (Wood *et al.*, 2000, Table 20). The effects on yield have been masked by higher input use, which increases farm production costs significantly and reduces farm income (Fig. 1.2).

Reducing natural capital by:

- Damage to natural environments important for local ecosystem stability and agricultural production (e.g. wetlands).
- Increased risks of natural disasters (flooding and droughts).
- Reduced long-term capacity to supply food needs through domestic production, due to reduced land area for production and reduced productivity.
- Damage to wild aquatic resources (fish and aquatic animals such as frogs, snails and crabs, and aquatic plants such as lotus or reeds). These resources can be highly significant to the nutrition and income of rural communities, particularly for landless people.

Reversing or Reducing Degradation

Learning from bright spots

While the aggregate picture of land and water degradation is quite worrying, there are also many bright spots. The term 'bright spot' is used to describe a community (village, district or catchment) that has succeeded in stopping or reversing degradation while improving livelihoods. Examples from upper watersheds include conservation farming in the Philippines (Nilo, 2001) and Thailand, hillside conservation investment in East Africa (Rwanda, Kenya and Burundi), projects in Morocco, West Cameroon, and Fouta Djalon in Guinea. There is widespread adoption of specific technologies that have contributed to bright spot development, including conservation tillage (Mexico, Central America, Brazil, Argentina, Chile, Uruguay and Paraguay), perennial crops use (in the mountains of Himachal Pradesh, India, and on hillsides of southern Mexico and Central America), multi-storey gardens (in densely populated areas with volcanic soils in Indonesia and southern China), and perennial plantations in areas of low population density with fragile soils (Malaysia, India, southern Thailand and the Philippines) (Scherr and Yadav, 1996).

One review of locations with sustainable agricultural practices documented 250 bright spots (Pretty and Hine, 2001). Rehabilitation has occurred in parts of South America and China where rainfed agriculture with legumes, organic and chemical fertilizer, and no-tillage practices are well developed. Bright spots in salinized areas include modern irrigation technology in Jordan, effective irrigation systems in Mexico, and the expanding small-scale irrigation in semi-arid areas of Africa and the Andes (Scherr and Yadav, 1996). A popular view is that smallholder farmers, often on poor land with not much water, can improve productivity of their farm only slowly and incrementally, if at all. That view results from looking at statistics and averages, but is refuted by leading examples such as the ones above. Documented examples of indigenous knowledge include a Zimbabwean farmer (Witoshynsky, 2000) and two South African farmers (Auerbach, 1999; De Lange and Penning de Vries, 2003), who keep as much water as possible on the farm (infiltration, ponds), keep the soil covered with a variety of plants or mulch (soil conservation, integrated pest management) and create a positive nutrient balance. It is important to note that these leading individuals underline that in 'transferring' their approach to others, the technical part is much easier than the challenge of creating a new 'attitude' to farming and to the management of natural resources and human, social and financial capitals. A search for bright spots in Africa yielded nine examples of difficult ecological and social situations where communities had taken initiatives and developed profitable activities (Penning de Vries, 2005). An in-depth analysis of Asian bright spots (Noble *et al.*, 2006) confirmed that some communities have independently reversed degradation of natural and social resources and that stimulation by external agents can be effective for upscaling. Bossio *et al.* (chapter 14, this volume) show considerable exosystem benefits of bright spots.

Approaches to Creating Bright Spots

Integrated analysis of degradation problems and solutions

Integrated land and water management approaches provide a comprehensive framework for countries to manage land and water resources in a way that recognizes political and social factors as well as the need to protect the integrity and function of ecological systems. These approaches emphasize cross-sectoral and broad stakeholder participation in land and water management planning and implementation.

The need for a paradigmatic shift from a single-sector approach to an integrated land and water management approach is supported by experiences from both developed and developing countries. Although it often leads to short-term economic gains, the single-sector approach to land and water management can result in long-term environmental degradation because it fails to account for the complex linkages among various ecosystem components. The single-sector approach typically seeks to maximize the benefits of one sector, such as irrigated agriculture, without considering the impacts on other sectors. In addition, this approach tends to rely heavily on technical and engineering solutions, making little or no attempt to address related policy and institutional issues.

Development activities in the Senegal River Valley highlight many of the unintended environmental and social impacts of the single-sector approach to land and water management. Two dams were constructed on the Senegal River in the 1970s to support intensive rice production, electricity generation and year-round navigation. Environmental and social considerations were not fully addressed in the design of these projects. As a result, the projects' initial economic success, in terms of rice production and electricity, has been overshadowed by rising environmental and social costs. About 50% of the irrigation fields have been lost to soil salinization; dams and dykes have reduced traditional grazing lands from 80,000 to 4000 ha; water pollution from pesticides and other agrochemicals is prevalent; and fish production in the river and estuary has dropped by 90% (Pirot *et al.*, 2000).

The off-site economic impacts of degradation are likely to be quite significant, but in most cases they are still hard to quantify (Enters, 1998). Yet such externalities need to be internalized for proper valuation of degradation. Many externalities must be negotiated directly, while others can be influenced by changing prices, for example through taxes on pollutants, removal of water subsidies, etc. As long as negative externalities are not internalized, it is unrealistic to expect land and water users to respond to downstream degradation problems.

Technologies and management practices that are cheaper and demand less labour

With respect to land and water, past technological developments have focused on ways to increase their usefulness and output in developed economies. Much has also been learned about the technical aspects of land and water conservation for low-income resource users. Technologies with the following characteristics are more adoptable and acceptable:

- Low cost, particularly in terms of cash.
- Familiar components.
- Amenable to incremental adoption (to allow for self-financing).
- Contribute to increased yields or reduced costs within 1–3 years.

Farming systems based on ecological principles could do a better job in generating and recycling organic matter and plant nutrients, and in protecting natural resources, than many modern but unbalanced systems. This includes the use of tree-based land use on hillsides. In many environments, there is a need to encourage landscape 'mosaics', with careful placement of landscape 'filters' and 'corridors' for the flow of nutrients, water, etc. through the system (Van Noordwijk *et al.*, 1998).

Because of the unique conditions at every site and for every situation, technologies will always require local adaptation. On-farm research and extension approaches that facilitate adaptative processes by greatly increasing the role of local users have been very effective. Technologies must be developed with a clear understanding of the socio-economic conditions of users, market conditions, roads and transport infrastructure, distribution systems, and so on.

Participatory planning and implementation

Many of the problems of land and water degradation can be traced to weak or non-existent institutions. Various types of institutions are required at the farm, community, regional and national levels. Learning lessons from successful institutional frameworks and institution-building efforts related to land and water degradation should be given high priority.

Basic approaches deal with different stakeholders, with learning to compromise and negotiate, and involve participatory development and research. Long-term involvement and the commitment of the key stakeholder groups, including the private sector, are required. Institutional issues are most important but very complex. There may be a need for collective investments by user groups, such as for establishing shelterbelts or drainage systems, when these are beyond the capacity of individual farmers. Groups can also help to encourage and support one another to undertake investments on individual farms. Land-care programmes in Australia and South-east Asia have taken over much of the extension role through such groups, with only minimal public subsidies.

There is a growing recognition that self-financing by, and micro-credit for, smallholders can be very effective instruments for improving land and water management and for increasing household food security. Of crucial importance to facilitating these mechanisms is the creation of an enabling socio-political and economic environment and a legal framework. Improvement of these conditions, tailored to the specific needs of an area, can be very successful without major public funds. There is a clear role for the private sector in protecting resources that they are using and in providing professional services.

Organizations of local watershed users are developing in many parts of the world. Some are federated or organized into cooperatives to take action in policy negotiations. A very successful example of local action is in the WaterWatch programmes that have spread through the Andes, South-east Asia and elsewhere.

The critical role of enabling public policy

The creation of an enabling environment for smallholder farmers and planning agencies to adopt management practices that reduce land and water degradation and improve food security is crucial. A legal framework is needed to define what activities are allowed in a particular area, who is responsible for them and for the state of a resource, and who oversees this process. Then the legal framework must be implemented effectively. Internationally accepted standards are needed on maximum contamination of soil and water that is used for different purposes (Hannam and Boer, 2001).

Within the arena of law and politics, an important issue is to provide smallholders with secure tenure or long-term arrangements for land use, and water users with assured rights to this resource. The absence of such arrangements is an important constraint for farmers to mobilize funds and to invest them in their farms. Assuring long-term rights to land and water is a necessary, if not always sufficient, action that is needed to assure poor people of a decent option to earn a living through agriculture and to halt degradation.

Priority Actions

Priority actions in setting policies

Five priority actions at the policy level were proposed elsewhere (Penning de Vries *et al.*, 2003) for countries to enable them to simultaneously enhance food security and environmental security. These actions are: (i) mainstreaming integrated land and water management approaches; (ii) strengthening enabling environments; (iii) wider adoption of supportive management practices and environmentally sound technologies; (iv) expansion and acceleration of capacity-development activities; and (v) strengthening of partnerships at the local, national and international levels to provide a mechanism for a coordinated response to issues of food and environmental security.

Priority actions in research

Even though much knowledge has been collected about food and environmental security and particularly about land and water resource management, there are still important gaps that hinder the ability and potential capacity of scientists to assist policy makers and farmers. To increase this ability, key issues for research are identified in the following areas: (i) improving food security; (ii) mechanisms to alleviate poverty; (iii) increasing ecosystem goods and services; (iv) improved interactions between these areas; and (v) legal frameworks to enable or facilitate change.

Food security

- How can land and water productivity be improved in fallow systems with problem soils when the fallow period is shortened (e.g. the introduction of legumes to restore soil fertility and limit weed invasion or through the integration of crops and livestock to maximize benefits from such resources)? What is the best way to increase soil available phosphorus for leguminous species?
- How to intensify rainfed agriculture without increasing hazards of off-site effects (pollution of the water, siltation and reservoir eutrophication), e.g. a balanced nutrient supply, safe and sustainable methods of weed, disease and pest control.
- How can land productivity be improved in areas of low-quality or depleted soils, without causing soil degradation (e.g. agro-ecological practices based on soil cover and nutrient cycling, or agroforestry)?
- How can water productivity be improved in areas of surface water scarcity without causing land degradation (e.g. salinization) or introducing water-borne diseases (such as malaria), e.g. increased crop water-use efficiency, water harvesting, groundwater irrigation using treadle pumps, bucket and drip sets?
- In what specific ways does ecosystem health in the surrounding rural landscape (including water, non-cropland land use and natural vegetation resources) affect agricultural productivity in different types of agro-ecosystems, and what landscape features are especially important to conserve or enhance from a farming perspective?
- How can sustainable aquaculture be developed and improved at the farm level to improve protein availability?
- How can deficiencies of micronutrients be reduced in food and feed, particularly in the nutrition of vulnerable groups?

Poverty Reduction

- How do non-agricultural employment and income stimulate agriculture in marginal lands?
- What impacts do subsidies (on fertilizers, pesticides, electricity, water and credit) have

on agricultural production and land and water degradation?

- What water rights and water markets/mechanisms can protect the rights of the poor and favour a more efficient and equal allocation of water across uses and users, and how can these be developed?
- What are the costs and benefits of irrigation for the rural and urban poor?
- What are the most appropriate water-allocation procedures within river basins and within irrigation systems that encourage sustainable land and water conservation practices?
- What are the conditions under which poor farmers invest for improved land and water management?
- How can the rate and efficiency of technology transfer to farming communities and between farmers be increased, using traditional and new methods?
- To what extent do the poor depend on natural vegetation and how can this resource be better protected and managed for their use?

Environmental security: ecosystem goods and services

- What are the impacts of land and water degradation on the services produced by agroecosystems at landscape, regional, global scales (e.g. deforestation in the headwaters, loss of banded and riparian vegetation, degradation of the mangroves in the coastal zones)?
- How do agroecosystems produce their ecosystem services? What are the functions of landscape mosaics, patchiness and connectivity for the flows of water, sediments and nutrients? Where are the sources and the sinks, the corridors and the filters? Detailed mass balance studies are required to enable effective management.
- What are the critical threshold values for various characteristics beyond which agroecosystems are no longer resilient (e.g. the minimum rootable soil depth below which no crop can grow, or minimum river discharges)?
- What is the current status of land and water degradation and resource improvement (e.g. updating of the regional inventories, with a clearer definition of indicators)?
- How will global change impact on ecosystem services (e.g. increase in wind and water erosion, seawater intrusion)?
- How can we design agricultural production systems that more closely mimic the natural ecosystem structure and function, while still supplying needed products?
- How can land rehabilitation through agro-ecological practices stimulate C-sequestration and contribute to the reduction of global warming?
- How can degraded lands and waters be turned into valuable land for alternative purposes: forestry, infrastructure (recreational facilities), nature conservation, parks and aquaculture?

Improved interactions

- How can nutrients in food and in waste transported from rural areas to cities and rivers be recycled on a large scale?
- How can off-site effects be internalized in production systems? Are there options for interbasin and intercatchment transfer of incomes between upland farmers and water managers and city dwellers? How can users reward watershed protection services in the uplands?
- To what extent is government support required and effective on marginal lands to combat land and water degradation and improve land productivity?
- How can soil degradation issues related to C-sequestration and to regional or international transfers of nutrients in food and feed be included in global trade negotiations? How can water for crop production be made an explicit part of international commodity trade negotiations?

Legal frameworks

- How do various forms of ownership and access to land and water affect attitudes and opportunities for sustainable agriculture?
- How can food and environmental security be defined at different scales for use in

national legislative systems, to facilitate implementation and monitoring, and relate to international and regional frameworks?

- Develop context-specific 'model' legal systems, so that countries can accelerate their developments with examples, and organize training at the national level to do so.

The concept of Integrated Natural Resources Management (INRM; Sawyer and Campbell, 2003) gives a guideline to better understand and manage land and water degradation problems. The concept of bright spots suggests determining the generic elements in successful cases of development. Research should be focused on hotspots and marginal areas, where the interactions between land and water degradation, food and environmental insecurity and poverty are the most pronounced. Other characteristics for this research are:

- Utilizing existing knowledge. In the information disseminated about successful technologies and management strategies to reverse land and water degradation (the bright spots), there is a crucial need to distinguish generic knowledge from case-specific elements. Increasing the accessibility of existing information has great value.
- Holistic, people-centred research. Much of the research on resource management at the watershed and landscape levels, and on poverty issues in marginal areas, needs to focus on the people, while emphasizing gender perspectives. It should be participatory, involving various stakeholders. The studies should include quantitative as well as qualitative methodologies for data gathering.
- Integrated research on crop and natural resource management should be framed within a multi-scale catchment perspective. Up-scaling results from small areas to full catchments is possible, provided that large-scale processes and interactions are taken care of.
- Interdisciplinary research. A wide spectrum of disciplines need to exchange approaches, from ecological sciences (e.g. soil science, plant ecology, hydrology) to management sciences (e.g. agronomy, hydronomy), and social and health sciences. Interdisciplinarity requires sound monodisciplinary knowledge.
- Inter-institutional research. The need for a continuum from strategic to applied research requires the involvement of various institutions and organizations: universities, advanced research institutions, international and national research centres, extension services, non-governmental organizations and farmers' and resource users' organizations.
- Long-term monitoring to detect changes. Long-term monitoring is essential to examine the effects of low-frequency events (e.g. severe droughts or very heavy rainfall), and to determine the threshold values of clearly defined indicators of land and water quality, based on field assessments and remote-sensing observations. Even more than biophysical characteristics, social and economic characteristics are time dependent. A data-clearing house needs to be established to oversee quality and document the material provided from many sources, as well as the methods by which the values of indicators are determined and the procedures of sampling.
- Experiments to understand change processes. Ecological sciences and agricultural sciences cannot be based solely on monitoring. To learn about the key processes, how they are controlled, and their on- and off-site effects, also requires experimental and manipulative approaches (e.g. paired experimental catchments with different agricultural practices).
- Models to simulate and predict changes. Based on existing, long-term monitoring and experimental data, and realistic scenarios of land use and climatic changes, models enable the exploration of the consequences of land and water degradation or rehabilitation. Independently validated ecological, hydrological, land use, crop growth and socio-economic models need to be coupled to predict interactions between ecological services, food security and poverty.

Notes

[1] An earlier version of this paper was presented as a keynote address to the 29th Brazilian Soil Science Congress, Sao Paulo, Brazil, 14 July, 2003, and draws heavily on Penning de Vries *et al.* (2003). We thank Dr D. Bossio for valuable comments.

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