CHAPTER 12

Agriculture and the environment: changing pressures, solutions and trade-offs

12.1 Introduction

Agriculture places a serious burden on the environment in the process of providing humanity with food and fibres. It is the largest consumer of water and the main source of nitrate pollution of groundwater and surface water, as well as the principal source of ammonia pollution. It is a major contributor to the phosphate pollution of waterways (OECD, 2001a) and to the release of the powerful greenhouse gases (GHGs) methane and nitrous oxide into the atmosphere (IPCC, 2001a). Increasingly, however, it is recognized that agriculture and forestry can also have positive externalities such as the provision of environmental services and amenities, for example through water storage and purification, carbon sequestration and the maintenance of rural landscapes. Moreover, research-driven intensification is saving vast areas of natural forest and grassland, which would have been developed in the absence of higher crop, meat and milk yields. But conversely, intensification has contributed to the air and water pollution mentioned above (Nelson and Mareida, 2001; Mareida and Pingali, 2001), and in some instances reduced productivity growth because of soil and water degradation (Murgai, Ali and Byerlee, 2001).

Quantification of the agro-environmental impacts is not an exact science. First, there is considerable debate on their spatial extent, and on the magnitude of the current and long-term biophysical effects and economic consequences of the impact of agriculture. Much of the literature is concerned with land degradation, especially water erosion. Moreover, most of the assessments are of physical damage, although a few attempts have been made to estimate the economic costs of degradation as a proportion of agricultural GDP. Scherr (1999) quotes estimates of annual losses in agricultural GDP caused by soil erosion for a number of African countries, which can be considerable. Unfortunately these aggregate estimates can be misleading, and policy priorities for limiting impacts based on physical damage may not truly reflect the costs to the economy at large. Second, the relative importance of different impacts may change with time, as point sources of pollution are increasingly brought under control and non-point sources become the major problem. Lastly, offsite costs can be considerably greater than onsite costs.

These important analytical limitations are apparent from recent estimates of the external environmental costs of agriculture in various developed countries given in Pretty *et al*. (2001). These estimates suggest that in developing countries over the next 30 years greater consideration should be given to air pollution and offsite damage because their costs may exceed those of land and water pollution, loss of biodiversity and onsite damage. It should be noted that a large proportion of these environmental costs stems from climate change and its impacts, which are still very uncertain (see Chapter 13).

It is generally accepted that most developing countries will increasingly face the type of agro-environmental impacts that have become so serious in developed countries over the past 30 years or more. The commodity production and input use projections presented in Chapters 3 and 4 provide an overall framework for assessing the likely impacts of agricultural activities on the environment over the next 30 years in developing countries. Several large developing countries already have average fertilizer and pesticide application rates exceeding those causing major environmental problems in developed countries. Similarly, some developing countries have intensive livestock units as large as those in Europe and North America that are regarded as serious threats to waterbodies (OECD, 2001a).

Moreover, the experience of agro-environmental impacts in developed countries can give advance warning to developing countries where agro-ecological conditions are similar to those in OECD countries. Developing countries are likely to face similar problems when adopting similar patterns of intensification. They can use the experience of developed countries to identify some of the policy and technological solutions to limit or avoid negative agro-environmental impacts, and to identify the trade-offs. They can also estimate the economic costs (externalities) of the agro-environmental impacts of intensive agriculture that are not currently reflected in agricultural commodity prices, and these costs can provide a basis for policy and technology priority setting.

It will be argued that higher priority than is currently the case should be given to lowering agriculture's impact on air and water. The remainder of this chapter assesses the changing pressures on the environment from agriculture, using the projections for land, water, agrochemical input and technological change given in earlier chapters. It examines the main technology and policy options for limiting agriculture's negative impacts on the environment and widening its positive ones. Finally, it considers the range of situations and trade-offs that may influence the uptake of these options. The important issue of climate change is examined both here and in Chapter 13. This chapter examines the role of agriculture as a driving force for climate change, while Chapter 13 examines the impact of climate change on agricultural production and food security.

12.2 Major trends and forces

It is clear from the crop production projections presented in Chapter 4 that the key issue for the future is the environmental pressure from intensification of land use, rather than land cover or land use changes alone. Some 80 percent of the incremental crop production in developing countries will come from intensification and the remainder from arable land expansion (Table 4.2). Thus the dominant agro-environmental costs and benefits over the projection period will continue to be those stemming from the use of improved cultivars and higher inputs of plant nutrients and livestock feeds, together with better nutrient management and tillage practices, pest management and irrigation. Nonetheless, extensification of agriculture in environmentally fragile "hot spots" or areas high in biodiversity will also remain of continuing concern.

The positive benefits of these changes will include a slowdown of soil erosion and at least a slower increase in pollution from fertilizers and pesticides. Likely outcomes on the negative side are a continuing rise in groundwater nitrate levels from poor fertilizer management, further land and yield losses through salinization, and growing air and water pollution from livestock.

The main agro-environmental problems fall into two groups. First, there are those that are global in scale such as, for example, the increase in atmospheric concentrations of the GHGs carbon dioxide (CO_2) through deforestation, and nitrous oxide (N_2O) arising from crop production (Houghton *et al.*, 1995; Mosier and Kroeze, 1998). The second group of problems is found in discrete locations of the major continents and most countries, but at present has no substantive impact at the global level. Examples are the salinization of irrigated lands and the buildup of nitrate fertilizer residues in groundwater and surface water. These problems first emerged in the developed countries in the 1970s as a consequence of agricultural intensification. However, they have become of increasing importance in some developing countries during the past decade or so, and are destined to become more widespread and more intense unless there is a break from current policy and technological trends.

Most of the negative impacts from agriculture on the environment can be reduced or prevented by an appropriate mix of policies and technological changes (see, for example, UN, 1993; Alexandratos, 1995; Pretty, 1995; and Conway, 1997). There is growing public pressure for a more environmentally benign agriculture. Countries also have to comply with the WTO Agreement on Agriculture and the UNCED Conventions (particularly the Framework Convention on Climate Change). This forces countries to reduce commodity price distortions and input subsidies, and encourages them to remove other policy interventions that tend to worsen agro-environmental impacts, and to integrate environmental considerations explicitly into agricultural policies.

At the national level, there is now a range of policy options available to correct past agro-environmental mistakes and to prevent or limit future ones. The main problems were first recognized in those developed countries that embarked on agricultural intensification in the 1940s and 1950s, e.g. France, the United Kingdom and the United States. These countries started to formulate corrective measures soon afterwards. Their experience can help other countries embarking on intensification to avoid or moderate some of the problems. Some developing countries, for example, have introduced institutional mechanisms to promote environmentally benign technologies more rapidly than the developed countries at a comparable point of economic development. Moreover, the responses have not been only at the public sector level. Farmers in both developed and developing countries have also made a significant contribution by spontaneously creating or adopting environmentally benign technologies or management practices.

At the international level, there is now wide endorsement of the precautionary principle, under which countries accept the need to introduce corrective actions at an early stage and possibly before all of the scientific justification is in place (UN, 1993). International action has also been taken to strengthen research on the biophysical changes that agriculture is causing (Walker and Steffen, 1999), and to monitor the key indicators of agro-ecosystem health (ICSU/UNEP/FAO/UNESCO/WMO, 1998; OECD, 1991, 2001b) so as to understand and give advance warning of any threats to agricultural sustainability.

12.3 Changing pressures on the environment

12.3.1 Agriculture's contribution to air pollution and climate change

Public attention tends to focus on the more visible signs of agriculture's impact on the environment, whereas it seems likely that the non-visible or less obvious impacts of air pollution cause the greatest economic costs (Pretty *et al.*, 2001). Agriculture affects air quality and the atmosphere in four main ways: particulate matter and GHGs from land clearance by fire (mainly rangeland and forest) and the burning of rice residues; methane from rice and livestock production; nitrous oxide from fertilizers and manure; and ammonia from manure and urine.

Pollution from biomass burning. Soot, dust and trace gases are released by biomass burning during forest, bush or rangeland clearance for agriculture. Burning is traditionally practised in "slash and burn" tropical farming, in firing of savannah regions by pastoralists to stimulate forage growth and in clearing of fallow land and disposing of crop residues, particularly rice. This burning has had major global impacts and has caused air pollution in tropical regions far away from the source of the fires.

Two developments should result in an appreciable fall in air pollution from biomass burning. Deforestation is often achieved by burning, or fire is used after timber extraction to remove the remaining vegetation (Chapter 6). The projected reduction in the rate of deforestation will slow down the growth in air pollution. The shift from extensive to intensive livestock production systems (Chapter 5) will reduce the practice of rangeland burning under extensive grazing systems, although the latter systems seem likely to remain dominant

Table 12.1 Agriculture's contribution to global greenhouse gas and other emissions

Gas	Carbon dioxide	Methane	Nitrous oxide	Nitric oxides	Ammonia
Main effects	Climate change	Climate change	Climate change	Acidification	Acidification Eutrophication
Agricultural source (estimated % contribution to total global emissions	Land use change, especially deforestation	Ruminants (15)	Livestock (including manure applied to farmland) (17)	Biomass burning (13)	Livestock (including manure applied to farmland (44)
		Rice production (11)	Mineral fertilizers (8)	Manure and mineral fertilizers (2)	Mineral fertilizers (17)
		Biomass burning (7)	Biomass burning (3)		Biomass burning (11)
Agricultural emissionsas % of total anthropogenic sources	15	49	66	27	93
Expected changes in agricultural emissions to 2030	Stable or declining	From rice: stable or declining From livestock: rising by 60%	35-60% increase		From livestock: rising by 60%

Main sources: Column 2: IPCC (2001a); column 3: Lassey, Lowe and Manning (2000); columns 4, 5 and 6: Bouwman (2001); FAO estimates.

in parts of sub-Saharan Africa. The growth in the contribution of crop residues may also slow down because of the projected very slow growth in rice production (Chapters 3 and 4). Climate change itself, however, may cause temperatures to rise in the dry season, increasing fire risks and thus increasing pollution from biomass burning in some areas (Lavorel *et al.*, 2001).

Greenhouse gas emissions. For some countries, the contribution from agriculture to GHG emissions is a substantial share of the national total emissions, although it is seldom the dominant source. Its share may increase in importance as energy and industrial emissions grow less rapidly than in the past while some agricultural emissions continue to grow (Table 12.1). There is increasing concern not just with carbon dioxide but also with the growth of agricultural emissions of other gases such as methane, nitrous oxide and ammonia arising from crop and livestock production. In some countries these can account for more than 80 percent of GHG emissions from agriculture.

The conversion of tropical forests to agricultural land, the expansion of rice and livestock production and the increased use of nitrogen fertilizers have all been significant contributors to GHG emissions. Agriculture now contributes about 30 percent of total global anthropogenic emissions of GHGs, although large seasonal and annual variations make a precise assessment difficult (Bouwman, 2001). Tropical forest clearance and land use change were major factors in the past for carbon dioxide emissions, but are likely to play a smaller role in the future (see Chapters 4 and 6). More attention is now being given to methane (CH_4) and nitrous oxide (N_2O), since agriculture is responsible for half or more of total global anthropogenic emissions of these GHGs (Table 12.1).

Methane from ruminant and rice production. Methane is a principal GHG driving climate change. Its warming potential is about 20 times more powerful than carbon dioxide.[1] Global methane emissions amount at present to about 540 million tonnes p.a., increasing at an annual rate of 20-30 million tonnes. Rice production currently contributes about 11 percent of global methane emissions. Around 15 percent comes from livestock (from enteric fermentation by cattle, sheep and goats and from animal excreta). The livestock contribution can be higher or lower at the national level depending on the extent and level of intensification. In the United Kingdom and Canada the share is over 35 percent.

The production structure for ruminants in developing countries is expected to increasingly shift towards that prevalent in the industrial countries. The major share of cattle and dairy production will come from feedlot, stall-fed or other restricted grazing systems and by 2030 nearly all pig and poultry production will also be concentrated in appropriate housings. Much of it will be on an industrial scale with potentially severe local impacts on air and water pollution.

The livestock projections in this report (Chapter 5) entail both positive and negative implications for methane emissions. The projected increase in livestock productivity, in part related to improvements in feed intake and feed digestibility, should reduce emissions per animal. Factors tending to increase emissions are the projected increase in cattle, sheep and goat numbers and the projected shift in production systems from grazing to stall-feeding. The latter is important because storage of manure in a liquid or waterlogged state is the principal source of methane emissions from manure, and these conditions are typical of the lagoons, pits and storage tanks used by intensive stall-feeding systems. When appropriate technologies are introduced to use methane in local power production, as has been done in some South and East Asian countries, the changes can be beneficial. If emissions grow in direct proportion to the projected increase in livestock numbers and in carcass weight or milk output (see Chapter 5), global methane emissions could be 60 percent higher by 2030. Growth in the developed regions will be slow, but in East and South Asia emissions could more than double, largely because of the rapid growth of pig and poultry production in these regions.

Rice cultivation is the other major agricultural source of methane. The harvested area of rice is projected to expand by only about 4.5 percent by 2030 (Table 4.11) depending on yield growth rates, and possibly on the ability of technological improvements to compensate for climate-change-induced productivity loss if this becomes serious (Wassmann, Moya and Lantin, 1998). Total methane emissions from rice production will probably not increase much in the longer term and could even decrease, for two reasons. First, about half of rice is grown using almost continuous flooding, which maintains anaerobic conditions in the soil and hence results in high methane emissions. However, because of water scarcity, labour shortages and better water pricing, an increasing proportion of rice is expected to be grown under controlled irrigation and better nutrient management, causing methane emissions to fall. Second, up to 90 percent of the methane from rice fields is emitted through the rice plant. New high-yielding varieties exist that emit considerably less methane than some of the widely used traditional and modern cultivars, and this property could be widely exploited over the next ten to 20 years (Wang, Neue and Samonte, 1997).

Nitrous oxide. Nitrous oxide (N_2O) is the other powerful GHG for which agriculture is the dominant anthropogenic source (Table 12.2). Mineral fertilizer use and cattle production are the main culprits. N_2O is generated by natural biogenic processes, but output is enhanced by agriculture through nitrogen fertilizers, the creation of crop residues, animal urine and faeces, and nitrogen leaching and runoff. N_2O formation is sensitive to climate, soil type, tillage practices and type and placement of fertilizer. It is also linked to the release of nitric oxide and ammonia, which contribute to acid rain and the acidification of soils and drainage systems (Mosier and Kroeze, 1998). The current agricultural contribution to total global nitrogen emissions is estimated at 4.7 million tonnes p.a., but there is great uncer-

1 Power is measured in terms of the global warming potential (GWP) of a gas, taking account of the ability of a gas to absorb infrared radiation and its lifetime in the atmosphere.

Table 12.2 Global N_2O emissions

Million tonnes N p.a.		Mean value		Range	
Natural sources					
Oceans		3.0		1-5	
Soils total, of which:		6.0		3.3-9.7	
Tropical soils	Wet forest		3.0		2.2-3.7
	Dry savannahs		1.0		0.5-2.0
Temperate soils	Forests		1.0		0.1-2.0
	Grasslands		1.0		0.5-2.0
Subtotal natural sources		**9.0**		**4.3-14.7**	
Anthropogenic sources					
Agriculture total, of which:		4.7		1.2-7.9	
Agricultural soils, manure, fertilizer			2.1		0.4-3.8
Cattle and feedlots			2.1		0.6-3.1
Biomass burning			0.5		0.2-1.0
Industry		1.3		0.7-1.8	
Subtotal anthropogenic sources		**6.0**		**1.9-9.6**	
Total all sources		**15.0**		**6.2-24.3**	

Source: Mosier and Kroeze (1998), modified using Mosier *et al.* (1996).

tainty about the magnitude because of the wide range in estimates of different agricultural sources (Table 12.2).

Nitrogen fertilizer is one major source of nitrous oxide emissions. The crop projections to 2030 imply slower growth of nitrogen fertilizer use compared with the past (Table 4.15 and Daberkov *et al.*, 1999). Depending on progress in raising fertilizer-use efficiency, the increase between 1997/99 and 2030 in total fertilizer use could be as low as 37 percent. This would entail similar or even smaller increases in the direct and indirect N_2O emissions from fertilizer and from nitrogen leaching and runoff. Current nitrogen fertilizer use in many developing countries is very inefficient. In China, for example, which is the world's largest consumer of nitrogen fertilizer, it is not uncommon for half to be lost by volatilization and 5 to 10 percent by leaching. Better onfarm fertilizer management, wider regulatory measures and economic incentives for balanced fertilizer use and reduced GHG emissions, together with technological improvements such as more cost-effective slow-release formulations should reduce these losses in the future.

Livestock are the other major source of anthropogenic nitrous oxide emissions (Mosier *et al.*, 1996; Bouwman, 2001). These emissions arise in three ways.

First, from the breakdown of manure applied as fertilizer, primarily to crops but also to pastures. The proportion of manure thus used is difficult to estimate, but it is probably less than 50 percent. Moreover, there are opposite trends in its use. In the developed countries, growing demand for organic foods, better soil nutrition management and greater recycling is favouring the increased use of manure. In the developing countries, with a strong growth in industrial-scale livestock production separate from crop production, and with decreasing labour availability, there is a trend to rely more on mineral fertilizers to maintain or raise crop yields. The second source is dung and urine deposited by grazing animals. The emissions from this source are higher for intensively managed grasslands than for extensive systems (Mosier *et al.*, 1996). Similarly, emissions from animals receiving low-quality feeds are likely to be less than with higher-quality feeds. Since shifts are expected from extensive to intensive production systems and from low- to higher-quality feeds, it can be assumed that there will be an increase in N_2O emissions from deposited dung and urine. The third source is from the storage of excreta produced in stall-feeding or in intensive production units. This may produce a reduction in emissions since, on average, stored excreta produce about half as much N_2O as excreta deposited on pastures (Mosier *et al.*, 1996).

Changes in manure production over time have been estimated using the projected growth in livestock populations (allowing for differences between cattle, dairy, sheep and goats, pigs and poultry). The amounts per head have been adjusted on a regional basis to allow for projected changes in carcass weight and milk output. Emission rates have been adjusted for the assumed shifts from extensive to stall-fed systems. Based on these assumptions and estimates, the total production of manure is projected to rise by about 60 percent between 1997/99 and 2030. However, N_2O emissions are projected to rise slightly more slowly (i.e. by about 50 percent) because of the switch from extensive to stall-fed systems. This relative environmental gain from intensification has to be seen against the rise in ammonia and methane emissions and the probable growth in point-source pollution that the intensive livestock units will generate. This latter cannot be quantified but is a very serious problem in a number of developed and developing countries (de Haan, Steinfeld and Blackburn, 1998).

Ammonia. Agriculture is the dominant source of anthropogenic ammonia emissions, which are around four times greater than natural emissions. Livestock production, particularly cattle, accounts for about 44 percent, mineral fertilizers for 17 percent and biomass burning and crop residues for about 11 percent of the global total (Bouwman *et al.*, 1997; Bouwman, 2001). Volatilization rates from mineral fertilizers in developing countries are about four times greater than in developed countries because of higher temperatures and lower-quality fertilizers. Losses are even higher from manure (about 22 percent of the nitrogen applied).

Ammonia emissions are potentially even more acidifying than emissions of sulphur dioxide and nitrogen oxides (Galloway, 1995). Moreover, future emissions of sulphur dioxide are likely to be lower as efforts continue to reduce industrial and domestic emissions and improve energy-use efficiency, whereas there is little action on reducing agriculture-related emissions. The ammonia released from intensive livestock systems contributes to both local (Pitcairn *et al.*, 1998) and longer-distance deposition of nitrogen (Asman, 1994). This causes damage to trees and acidification and eutrophication of terrestrial and aquatic ecosystems, leading to decreased nutrient availability, disruption of nitrogen fixation and other microbiological processes, and declining species richness (UNEP/RIVM, 1999).

The livestock projections of this study are based on changes in both animal numbers and in productivity, as determined by changes in carcass weight or milk output per animal. It is assumed that the volume of excreta per animal, which is the main source of the ammonia, increases over time in proportion to carcass weight, which in turn is a reflection of the increase in the use of feed concentrates. Table 12.3 gives estimates of ammonia emissions in 1997/99 and 2030 using these assumptions. The projected increase for the developing countries (80 percent) is significantly higher than the increase (50 percent) given in Bouwman *et al.* (1997).

These projections have three main environmental implications. First, all the developing regions potentially face ammonia emission levels that have caused serious ecosystem damage in the developed countries. Second, emissions may continue to rise in the developed countries, adding to the already serious damage in some areas. And third, in East Asia and Latin America, a high proportion of the emissions will come from intensive pig production systems, in which emission reduction is more difficult. Since many of these intensive production units are located where there is a large demand, the downwind and downstream effects are likely to be concentrated near large urban populations, often on river plains and coastal plains that are already subject to a high chemical and particulate pollution load.

12.3.2 Agriculture's impact on land

In recent decades the most important environmental issues concerning land have been land cover change, particularly deforestation, and land use intensification, especially its impact on land degradation. The future picture concerning land

Table 12.3 Ammonia emissions implied by the livestock projections

	Number of animals (in millions) 1997/99	2030	Emissions NH_3 ('000 tonnes N p.a.) 1997/99	2030
			World	
Total			**30.34**	**48.60**
Cattle and buffalo	1 497	1 858	13.09	19.51
Dairy	278	391	5.35	9.98
Sheep and goats	1 749	2 309	2.02	3.50
Pigs	871	1 062	6.62	9.25
Poultry	15 119	24 804	3.27	6.35
			Developing countries	
Total			**21.35**	**38.55**
Cattle and buffalo	1 156	1 522	9.33	15.34
Dairy	198	312	3.63	8.08
Sheep and goats	1 323	1 856	1.59	3.02
Pigs	579	760	4.52	7.02
Poultry	10 587	19 193	2.29	5.09
			Industrial countries	
Total			**6.67**	**7.24**
Cattle and buffalo	254	243	3.03	3.18
Dairy	41	44	1.02	1.21
Sheep and goats	341	358	0.33	0.34
Pigs	210	220	1.51	1.58
Poultry	3 612	4 325	0.78	0.93
			Transition countries	
Total			**2.32**	**2.80**
Cattle and buffalo	87	94	0.74	1.00
Dairy	39	35	0.69	0.69
Sheep and goats	85	95	0.10	0.14
Pigs	81	82	0.59	0.65
Poultry	920	1 287	0.20	0.32

Note: Figures for the base year are from Mosier and Kroeze (1998).

cover change is a continuing slowing down of the conversion of forests to areas for crop or livestock production; no appreciable change in grazing area; and continued growth of protected areas. However, in the case of land degradation, there are still widely differing opinions about future trends, and the empirical basis for making firm projections remains weak.

Land cover change. In the past much of the pressure for land cover change came from deforestation, but this is likely to slow down in future. The process of deforestation will continue in the tropics but at a decelerating rate, and in a number of major developing countries the extent of forest will actually increase. In Latin America, for example, governments have removed some of the policy distortions that encouraged large farmers and companies to create pastures on deforested land. However, deforestation by smallholders has not been reduced. In West Africa, almost no primary rain forest is left, and over 80 percent of the population is still rural and growing at 2.5-3 percent p.a. – a situation that is likely to continue until non-agricultural employment opportunities are found.

The total extent of grassland is likely to decrease. In most developing regions the general trend is away from extensive grazing towards mixed farming and improved pastures or intensive feedlot and stall-fed systems. It is assumed that there will be no substantial development of new grassland. Some of the more marginal rangelands and pastures are likely to be abandoned as herders and other livestock producers leave the land for better-paid jobs outside agriculture, as happened in parts of Europe after about 1950 (CEC, 1980). In the absence of grazing pressure these areas will revert to forest or scrub. Some of the better grazing land will be converted to cropland or urban land, with the loss being compensated by improving productivity on the remaining land rather than by clearing new land. At the national level some countries will diverge from this global picture. Countries such as China, some Commonwealth of Independent States countries and parts of South America still have the potential for major increases in the use of natural grasslands (Fan Jiangwen, 1998).

Net arable land expansion in developing countries is projected to fall from about 5 million ha p. a. over the past four decades to less than 3.8 million ha p.a. over the period to 2030 (Table 4.7). This net increase takes into account the area of cropland going out of use because of degradation, which some argue is in the order of 5 to 6 million ha p.a. (UNEP, 1997). It also takes into account land abandoned because it is no longer economically attractive to farm or as a result of changes in government policy, and land taken up by urbanization. It does not, however, take account of the area that is restored to use for reasons other than crop production, e.g. as part of agricultural carbon sequestration policies. In the future such areas could be substantial.

Even though an overall slowdown in the expansion of agricultural land is expected, there are three areas of concern. First, the frequency or intensity of cultivation of formerly forested slope lands will probably increase. Second, further drainage of wetlands will result in loss of biodiversity and of fish spawning grounds, with increased carbon dioxide but lower methane emissions. Third, high-quality cropland will continue to be lost to urban and industrial development.

Cultivation of slope lands. Uplands are particularly prone to water erosion where cultivated slopes are steeper than 10 to 30 percent, lack appropriate soil conservation measures and rainfall is heavy. Substantial areas of land are at risk (Bot, Nachtergaele and Young, 2000), although it is not possible to make global or even regional estimates of how much of this is currently cropped land. In Southeast Asia, land pressure caused by increasing population has extended the use of steep hill slopes particularly for maize production. This has led to a very significant increase in erosion on lands with slopes of over 20 percent (Huizing and Bronsveld, 1991).

There are two main environmental concerns for the future. First, more forest may be cleared for cultivation, resulting in the loss of biodiversity and increased soil erosion. Second, existing cultivated slopes may be cropped more intensively, leading to greater soil erosion and other forms of land degradation (Shaxson, 1998).

In countries such as Bhutan and Nepal with limited flat land left to develop, almost all of the additional land brought into cultivation in the future will be steep lands prone to erosion unless well terraced, or protected by grass strips, conservation tillage, etc. In Nepal, for example, soil erosion rates in the hills and mountains are in the range of 20 to 50 tonnes/ha/p.a. in agriculture fields and 200 tonnes/ha/p.a. in some highly degraded watersheds (Carson, 1992). Crop yields in these areas declined by 8 to 21 percent over the period 1970-1995. Such losses seem likely to continue, unless there are substantial changes in farmer incentives for soil conservation and wider knowledge at all levels of the economic and environmental benefits that conservation provides. In countries with less acute land pressure there may be a slowing down in the expansion of cropped slope lands, but there will still be pressures for the intensification of cultivation and hence the risk of greater erosion.

Deforestation of slope lands was a serious concern in the past but may slow down over the projection period. On the one hand, a good part of the 3.8 million ha annual net new cropland over the period to 2030 will probably come from forest conversion. A high proportion will have steep slopes and will be in zones with high rainfall, so the water erosion risk will be high unless suitable management techniques are adopted (Fischer, van Velthuizen and Nachtergaele, 2000). On the other hand, large areas of existing crop and grazing land – much of which is likely to be slope land – could revert to forest and scrub because of land abandonment and outmigration.

Reclamation of wetlands. Historically, the reclamation of wetlands has made a major contribution to agricultural growth and food security. Significant parts of the rich croplands of the Mississippi basin in the United States, the Po Valley in Italy and the Nile Delta in Egypt are reclaimed wetlands. The developing countries have over 300 million ha of natural wetlands that are potentially suitable for crop production. Some of the wetlands will inevitably be drained for crop production. Part will be in countries with relatively large land areas per capita but limited areas with adequate rainfall or irrigation potential, e.g. Senegal. Part will be in countries where much of the potential arable land is not well suited for sustainable agriculture because of steep slopes or thin, fragile soils, so the development of wetlands is therefore a more attractive option, e.g. Indonesia.

Wetlands are flat, and by definition well watered. In the case of some Sahelian countries they are potentially important contributors to food security (Juo and Lowe, 1986). Past experience in the inland valleys of the Sahelian belt suggest, however, that reclamation for agriculture has been of doubtful benefit despite huge international investments. Many irrigation schemes have failed through mismanagement and inadequate infrastructure maintenance, civil unrest and weak market development. The soils in this region are potentially productive once certain constraints are overcome, e.g. acid sulphate, aluminium and iron toxicity and waterlogging.

Assuming that the present rate of drainage of wetlands declines, the total conversion over the projection period will amount to a relatively small part of the 300 million ha they currently cover, but even this would carry some environmental risks. There may be damage to the hydrological functions of wetlands, such as groundwater recharge and natural flood relief, and disruption of migration routes and overwintering grounds of certain birds.

In central China, for example, around half a million ha of wetlands have been reclaimed for crop production since about 1950, contributing to a reduction of floodwater storage capacity of approximately 50 billion m^3 (Cai, Zhao and Du, 1999). There is strong evidence that wetland reclamation is responsible for about two-thirds of this loss in storage capacity, and thus for about two-thirds of the US$20 billion flood damage in 1998 (Norse *et al.*, 2001). Similar links have been established for the severe 1993 floods in the United States (IFMRC, 1994). Therefore it is important to introduce appropriate planning and regulatory mechanisms to ensure that any future wetland development is undertaken with the necessary safeguards, as is the case in the United States and a number of other developed countries (Wiebe, Tegene and Kuhn, 1995).

Loss of and competition for good arable land. As populations grow, much good cropland is lost to urban and industrial development, roads and reservoirs. For sound historic and strategic reasons, most urban areas are sited on flat coastal plains or river valleys with fertile soils. Given that much future urban expansion will be centred on such areas, the loss of good-quality cropland seems likely to continue. In fact the losses seem inevitable, given the low economic returns to farm capital and labour compared with non-agricultural uses. Such losses are essentially irreversible and in land-scarce countries the implications for food security could be serious.

Estimates of non-agricultural use of land per thousand persons range from 22 ha in India (Katyal *et al.*, 1997), to 15-28 ha in China (Ash and Edmunds, 1998) and to 60 ha in the United States (Waggoner, 1994). The magnitude of future conversions of land for urban uses is not certain, nor how much of it will be good arable land. There is no doubt, however, that losses could be substantial. In China, for example, the losses between 1985 and 1995 were over 2 million ha, and the rate of loss to industrial construction has increased since 1980 (Ash and Edmunds, 1998).

The projected increase in world population between 2000 and 2030 is some 2.2 billion.

Table 12.4 Global Assessment of Human-induced Soil Degradation (GLASOD)[2]

Region	Total land affected (million ha)	Percentage of region degraded	
		Moderate	Strong and extreme
Africa	494	39	26
Asia	747	46	15
Australasia	103	4	2
South America	243	47	10
Central America	63	56	41
Europe	219	66	6
North America	96	81	1
Total	1 964	46	16

Source: Oldeman, Hakkeling and Sombroek (1991).

Assuming that the conversion of land for non-agricultural purposes is an average of 40 ha per thousand persons, the projected loss on this account would be almost 90 million ha. Even assuming that all of this would be land with crop production potential, this would be only a fraction of the global balance of potential cropland that is as yet unused (see Chapter 4). However, in heavily populated countries such as China and India which have very limited potential for cropland expansion, even small losses could be serious. In China, this issue has been of growing concern for a number of years. Land loss to urban and industrial development in central and southern China has been partially compensated by the conversion of grasslands in the northeast to crop production (Ash and Edmunds, 1998). But although this new land is very fertile, the growing season is short and allows only one crop per year, compared with the two to three crops per year possible on the land lost in the central and southern areas. However, it seems likely that the global trading system will be able to meet China's potential food import needs to 2030 and beyond (Alexandratos, Bruinsma and Schmidhuber, 2000).

Land degradation.[3] The assessment of land degradation is greatly hindered by serious weaknesses in our knowledge of the current situation (Pagiola, 1999; Branca, 2001). According to some analysts, land degradation is a major threat to food security, it has negated many of the productivity improvements of the past, and it is getting worse (Pimentel *et al.*, 1995; UNEP, 1999; Bremen, Groot and van Keulen, 2001). Others believe that the seriousness of the situation has been overestimated at the global and local level (Crosson, 1997; Scherr, 1999; Lindert, 2000; Mazzucato and Niemeijer, 2001).

Area of degraded land. The most comprehensive global assessment is still the Global Assessment of Human-induced Soil Degradation (GLASOD) mapping exercise (Oldeman, Hakkeling and Sombroek, 1991; Table 12.4).

The results are subject to a number of uncertainties, particularly regarding the impact on productivity and the rates of change in the area and severity of degradation. A follow-up study for South Asia addressed some of the weaknesses of GLASOD. It introduced more information from national studies and greater detail on the different forms of degradation (FAO/UNDP/UNEP, 1994). The broad picture for South Asia remains similar in the two studies: 30-40 percent of the agricultural land is degraded to some degree, and water erosion is the most widespread problem (Table 12.5).

2 GLASOD defines four levels of degradation: light = somewhat reduced agricultural productivity; moderate = greatly reduced agricultural productivity; strong = unreclaimable at the farm level; extreme = unreclaimable and unrestorable with current technology.

3 Defined as a process that lowers the current or potential capabilities of the soil to produce goods or services, through chemical, physical or biological changes that lower productivity (Branca, 2001).

Table 12.5 Shares of agricultural land in South Asia affected by different forms of degradation

Type of land degradation	Percentage of agricultural land affected
Water erosion	25
Wind erosion	18
Soil fertility decline	13
Salinization	9
Lowering of the water table	6
Waterlogging	2

Source: FAO/UNDP/UNEP (1994), p. 50-51.

Despite these improvements in techniques of assessment, a number of serious difficulties remain in using them for perspective analysis. They are still heavily based on expert judgement, for entirely justified reasons. There is no clear consensus as to the area of degraded land, even at the national level. In India, for example, estimates by different public authorities vary from 53 to 239 million ha (Katyal *et al.*, 1997). Land degradation is very variable over small areas, e.g. as a consequence of differences in soil type, topography, crop type and management practice, so impacts are highly site specific. They can also be time specific: soil erosion impacts can vary in the short term because of interannual differences in rainfall, with no yield reductions in high rainfall years but appreciable losses in dry years (Moyo, 1998). Some forms of degradation are not readily visible, for example, soil compaction, acidification and reduced biological activity. Lack of data and analytical tools for measuring such differences prevents or limits estimation of their impact on productivity, and makes scaling up to the national or regional level problematic. There are no internationally agreed criteria or procedures for estimating the severity of degradation and most surveys do not make reliable assessments. Few if any countries make systematic assessments at regular intervals that permit estimation of rates of change. Finally, major changes in socio-economic conditions, improved market opportunities, infrastructure and technology over the medium to long term can induce farmers to overcome degradation (Tiffen, Mortimore and Gichuki, 1994).

Impact of degradation on productivity. Does degradation have a serious impact on onfarm productivity, and on offsite environments through wind and water dispersal of soil? Because degradation is normally a slow and almost invisible process, rising yields caused by higher inputs can mask the impact of degradation until yields are close to their ceiling. They thus hide the costs to farmers of falling input efficiency (Walker and Young, 1986; Bremen, Groot and van Keulen, 2001). In Pakistan's Punjab, for example, Murgai, Ali and Byerlee (2001) question whether technological gains can be sustained because of the severe degradation of land and water resources.

Moreover, the experimental methods commonly used to determine impacts on yields have a number of weaknesses (Stocking and Tengberg, 1999). Estimation of the economic costs can be equally complex. First, there may be impacts not just on yield levels, but on grain quality (e.g. drop in protein quality), yield stability or production costs or any combination of these (Lipper, 2000). Second, it is necessary to separate out the effect of the different factors involved in total factor productivity growth (Murgai, Ali and Byerlee, 2001). There are also offsite impacts such as siltation of streams and reservoirs, loss of fish productivity, raising water storage costs and the incidence of flood damage, and these are normally more serious than the onfarm impacts.

Given the above estimation difficulties, it is not surprising that there is little correspondence between global assessments of productivity loss and national or local realities. According to GLASOD, most areas in six states of the United States were classified as moderately degraded. According to the definition, this should result in reduced agricultural productivity. In reality, however, crop yields in these areas have been rising steadily for the past 40 years.

Crosson (1997) suggests that recent rates of land degradation and particularly soil erosion have had only a small impact on productivity, and argues that the annual average loss for cropland productivity since the mid-1950s was lower than 0.3 percent. Similarly, according to GLASOD there is almost no cultivated land in China that is not degraded in one way or another. Almost all the areas of rice cultivation in south and southeast China are classified as being affected by high or very high water erosion, and large wheat-growing areas southeast of Beijing are classified as suffering from medium levels of chemical deterioration (salinization). Yet, in spite of this, China was able to increase its wheat production between the early 1960s and mid-1990s from about 16 to 110 million tonnes, and its paddy production from 63 to 194 million tonnes. Moreover, more detailed assessments suggest that there has been little deterioration in China's (and Indonesia's) soils since the 1950s and they may have actually improved up to the 1980s (Lindert, 2000.) Water erosion from most rice fields is very low (Norse *et al.*, 2001). Nonetheless, rising yields may have masked productivity losses.

Oldeman (1998) estimates the global cumulative loss of cropland productivity at about 13 percent, but there are large regional differences. Africa and Central America may have suffered declines of 25 and 38 percent respectively since 1945. Asia and South America, on the other hand, may have lost only about 13 percent, while Europe and North America have lost only 8 percent. UNEP (1999) does not accept Crosson's assessment and argues that land degradation is so bad that it has negated many of the gains in land productivity of recent decades. Support for this view comes from detailed analysis of resource degradation under intensive crop production systems in the Pakistan and Indian Punjab (Murgai, Ali and Byerlee, 2001).

Three issues arise here. First, these estimates are global and regional averages, whereas the implications of degradation for agricultural production and food security are primarily local and national. On the one hand, there are complex trade-offs and compensatory mechanisms involved in some forms of degradation. A high proportion of eroded soil is redeposited elsewhere in the catchment area, where it tends to boost productivity, but it may also silt up reservoirs and irrigation canals. For example, in the United States some 45 percent is redeposited locally, and some 46 percent in lakes, reservoirs and other impoundments (Smith *et al.*, 2001). On the other hand, there are also a number of so-called hot spots where the degradation is already serious and could get worse (Scherr and Yadav, 1996). These hot spots include some of the developing countries' most fertile river basins (Table 12.6), which play a vital role in food security.

Second, the most visible degradation tends to be on marginal lands, whereas the bulk of food production occurs on more favourable lands, particularly irrigated areas (Norse, 1988). On such favoured lands relatively low rates of degradation could have large impacts on productivity and yields, although there are some grounds for concluding that this will not be the case. There is

Table 12.6 Regional hot spots of land degradation

Region	Salinization	Erosion
South and West Asia	Indus, Tigris and Euphrates river basins	Foothills of the Himalayas
East and Southeast Asia	Northeast Thailand and North China Plain	Unterraced slopes of China and Southeast Asia
Africa	Nile Delta	Southeast Nigeria, the Sahel, mechanized farming areas of North and West Africa
Latin America and the Caribbean	Northern Mexico, Andean highlands	Slopes of Central America, the semi-arid Andean Valley and the *cerrados* of Brazil

Source: Scherr and Yadav (1996).

growing evidence that farmers are able to adapt to environmental stress in ways that limit degradation (Mortimore and Adams, 2001; Mazzucato and Niemeijer, 2001).

Third, there are factors at work that may reduce degradation in the coming decades. These include the wider use of direct measures to prevent or reverse degradation (Branca, 2001), and indirect measures such as improved irrigation techniques and water pricing to reduce salinization. The spread of NT/CA will limit the damage caused by conventional tillage. Nonetheless the results from the Punjab show no grounds for complacency regarding the sustainability of some high-input crop production systems, and point to the need for increased fertilizer-use efficiency and reduced salinization.

Future areas of degraded land and loss of productivity. Will the area of degraded arable and pastoral land expand in the future, or deteriorate further, e.g. because of population pressure or the projected intensification of production?

Although the projections presented in Chapter 4 do not directly address the issue of land degradation, they do contain a number of features that can be used to assess how some forms of degradation may decline or become more serious in the future.

First, about one-third of the harvested area in developing countries in 2030 is projected to be *irrigated* land (Table 4.8), up from 29 percent in 1997/99. This is generally flat or well-terraced land with little erosion. However, parts may be at risk from salinization, particularly in more arid zones (Norse *et al.*, 2001). In addition, a quarter of the harvested *rainfed* land is estimated to have slopes of less than 5 percent, which are generally not prone to heavy water erosion. Their annual soil losses of around 10 tonnes per ha should be reduced where it is economically feasible to do so, but such rates could be tolerated for several hundred years before they have an appreciable impact on crop production. In all, around half of the cropland will not be markedly prone to soil erosion, although it may be subject to other forms of land degradation including salinization, nutrient mining, soil acidification and compaction.

Second, the global area of rainfed land under NT/CA could grow considerably, bringing benefits such as reduced soil erosion, reduced loss of plant nutrients, higher rainfall infiltration and better soil moisture-holding capacity (see Chapter 11 and Section 12.4.3 below). NT/CA will have positive effects on the physical, chemical and biological status of soils. Organic matter levels of soils, for example, are likely to rise. Organic matter is a major source of plant nutrients and is the glue that holds soil particles together and stabilizes the pore structure. Organic matter makes soils less vulnerable to wind erosion and functions as a sponge for holding water and slowing down its loss from the crop root zone by drainage or evaporation. Moreover, the nutrients added to the soil as organic residues are released more gradually than those from mineral fertilizers and are therefore less prone to leaching, volatilization or fixation (Avnimelech, 1986). In addition, higher soil organic matter levels are commonly associated with greater levels of humic acid, which increases phosphate availability and thus can be very beneficial in those areas with strongly phosphate-fixing soils found in sub-Saharan Africa and Latin America.

Third, fertilizer consumption and fertilizer-use efficiency are projected to rise. This will bring benefits in terms of higher soil fertility and soil organic matter levels. Soil erosion will diminish because of the positive impact on root proliferation, plant growth and ground cover of increased phosphate and potassium (associated with more balanced fertilizer inputs).

These conclusions are broadly consistent with projections made by the International Food Policy Research Institute (IFPRI) (Agcaoili, Perez and Rosegrant, 1995; Scherr and Yadav, 1996). That is, global losses to degradation are likely to be small, but losses could be significant in some localities and regions. However, soil productivity loss from land degradation could be much more serious if the above gains from NT/CA, greater fertilizer use and fertilizer-use efficiency, and other forms of soil and water conservation are less than we estimate, and crop yield growth slows appreciably, as projected in Chapter 4.

On the other hand, there are sound reasons to believe that some of the fragile lands most prone to degradation will be abandoned. This will not necessarily result in additional pressures for deforestation and cropland development, because high rates of urbanization and rural-urban migration are projected for the future. This outmigration could, for example, reduce degradation stemming from the cultivation of slope lands, and lower some of the pressure on grazing land in the Sahel and other semi-arid and arid areas.

This is likely to have similar effects to those experienced in western European countries from the 1950s and 1960s onwards (CEC, 1980; Baldock *et al.*, 1996), and in Eastern European countries since the 1990s. Here rural outmigration and the restructuring of agriculture led to the abandonment of steep slopes and other marginal land and reduced pressure to develop any more land. Substantial areas of marginal land were abandoned and reverted to forest or scrub. In France this amounted to around 3 percent p.a. in the 1960s and early 1970s (Faudry and Tauveron, 1975). In Italy around 1.5 million ha were abandoned in the 1960s, of which some 70 percent was slope land, with decreases of 20 percent in some provinces (CEC, 1980). The decline was very rapid, and closely related to sharp falls in agricultural employment.

Rural outmigration and agricultural restructuring have also been occurring in many developing countries and are projected to continue. This trend is most noticeable in countries such as China, where urbanization is accompanied by a shift to alternative income sources. It follows, therefore, that a significant percentage of the slope land cultivated at present could be abandoned over the next three decades in many developing countries, with a substantial proportion reverting to forest. However, in densely populated rural economies, such as Indonesia, where the rate of population growth is still over 2 percent p.a., population drift to cities has not significantly reduced the density of rural settlement, or improved the economic livelihoods of the majority of the rural population.

Desertification is a serious form of dryland degradation, given priority by the international community in the form of the United Nations Convention to Combat Desertification (UNCCD). In the 1970s and 1980s it was argued that the Sahara was spreading rapidly southwards as part of an irreversible expansion of the world's deserts. Since then, counter-arguments have been growing in force, backed up by strong empirical evidence from remote-sensing activities (Nicholson and Tucker, 1998; Prince, Brown de Colstoun and Kravitz, 1998). This has shown that the desert margins are quite dynamic because of natural climate variation. The problem is more one of localized dryland degradation because of overgrazing, excessive fuel collection, bad tillage practices and inappropriate cropping systems.

Nonetheless, there has been some expansion of the deserts and dryland degradation (Dregne and Chou, 1992). Degradation of vegetation and native habitat is the major reason for species extinction in many semi-arid and subhumid environments. Rapid rates of species loss, particularly of beneficial insects, birds and other predators may reduce the capacity for natural suppression of the pests, diseases and weeds that are among the greatest threats to current levels of agricultural production. However, quantification is not precise (Dregne and Chou, 1992). The most extreme estimates suggest that about 70 percent of the 3.6 billion ha of drylands are degraded, although this is likely to be an overestimate. More probing analysis is highlighting the resilience and adaptability of crop and livestock systems in vulnerable areas such as the Sahel (Behnke, Scoones and Kerven, 1993; Mortimore and Adams, 2001).

Looking to the future, there seem to be several ongoing positive forces that could have a significant effect. First, the contraction in extensive livestock production should take the pressure off some drylands and reduce dryland degradation. Second, gains in productivity on favourable lands should allow some of the marginal drylands to revert to range or scrub. Third, the spread of irrigation, water-harvesting techniques and measures to avoid or overcome salinization should improve the sustainability of dryland agriculture. Fourth, the continued adoption of NT/CA permits greater rainfall infiltration and improves soil moisture-holding capacity. Fifth, better drought- and grazing-tolerant crops and grasses will be created through gene transfer, although this is unlikely to have much impact before 2015. Sixth, countries such as China and India are making major efforts to restore degraded land in arid areas (Sinha, 1997). Finally, there are widespread efforts to restore saline and other degraded soils that have gone out of production. In the view of some analysts, restored lands could total 200-300 million ha by 2025 (GCSI, 1999). On the negative side, at least in the medium term, are the expansion or intensification of cropping in semi-arid areas and further losses from salinization.

Overgrazing has been one of the central environmental concerns related to livestock activities. It can lead to the degradation of grasslands and desertification in semi-arid areas, while on steep slopes it can cause serious soil erosion. Scherr and Yadav (1996) highlight overgrazing in parts of the Caribbean and North Africa, and the grazing of slopes in mid-altitude areas of Asia as areas of concern. UNEP's *Global Environment Outlook* (UNEP, 1997) also lays emphasis on devegetation and land degradation from overgrazing. However, gaseous emissions and water pollution from livestock systems could be of greater global and more widespread national concern than overgrazing, although the latter will remain a serious threat in some areas. This is consistent with the detailed analysis of the impact of livestock on the environment given in de Haan, Steinfeld and Blackburn (1998).

There is a growing consensus that the importance of overgrazing has been misjudged in the past, particularly in sub-Saharan Africa. This was in part caused by poor understanding of rangeland ecology, and in part by the lack of appreciation of traditional range management practices in arid and semi-arid areas (Behnke, Scoones and Kerven, 1993). The alleged overgrazing in the Sahel, for example, is mainly a consequence of natural climate variability, i.e. low rainfall in some years, and poor stock management rather than overstocking *per se* (Fleischhauer, Bayer and Lossau, 1998). There is very little lasting impact on the vegetation, which is more robust than once thought. In recent decades, however, the establishment of permanent watering-points and the restrictions placed on traditional migratory routes through border checks have led to greater impact in drought periods than probably occurred in the past. In Australia, for example, poor planning and management of water-holes have led to serious overgrazing and reductions in pasture species. The periodic overstocking that does occur is often the consequence of institutional and infrastructural problems constraining the marketing of livestock.

Looking ahead to 2030, it is reasonable to assume that overgrazing will not cause major increases in land degradation globally. Pastoralists will continue to move their livestock around to exploit spatial differences in growing conditions if they are allowed to. The lack of opportunities to raise the productivity of extensive livestock systems, and changing income sources and aspirations among livestock producers will continue to cause shifts to more intensive systems on the better lands closer to urban markets, or out of agriculture altogether. Finally, some of the institutional and infrastructural constraints that have encouraged overgrazing in the past will be reduced as growing urbanization and income growth stimulate market improvements.

12.3.3 Environmental dimensions of water use and water pollution by agriculture

Many water management and pollution issues have grown in importance in recent decades, such as growing competition with the urban and industrial sectors for the available water supply; poor irrigation water-use efficiency; overextraction of groundwater; reduced infiltration of rainwater into soils and reduced water recharge because of deforestation and land degradation; declining crop yields and water quality related to waterlogging and salinization; contamination of groundwater and surface water from fertilizers, pesticides and animal wastes; and the risk of greater aridity and soil moisture deficits towards the end of the projection period in some areas of sub-Saharan Africa and South Asia because of climate change.

Overextraction of groundwater. Overextraction of groundwater is widespread in both developed and developing countries. It arises when industrial and domestic and agricultural withdrawals of water exceed the rate of natural recharge. In some areas, particularly in the Near East/North Africa region, irrigation draws on fossil aquifers that receive little or no recharge at a level that is not sustainable (Gleick, 1994). In substantial areas of China and India groundwater levels are falling by 1-3 metres p.a. The economic and environmental consequences are serious and will get worse in the absence of appropriate responses. Irreversible land subsidence, especially in urban and peri-urban areas, causes serious structural damage to buildings, drainage systems, etc. Overextraction in coastal areas causes saltwater to intrude into freshwater aquifers, making them unfit for irrigation or drinking-water without costly treatment. Lowering of the water table increases pumping costs. It will take many years to achieve the investments and other changes required to limit overextraction, so several million ha of irrigated land may either go out of production or be faced with unsustainable operating costs.

Waterlogging and salinization. Both these problems are commonly related to irrigation mismanagement. Waterlogging restricts plant growth. It arises from overirrigation and inadequate drainage, and in many cases precedes salinization. Over 10 million ha are estimated to be affected by waterlogging (Oldeman, Hakkeling and Sombroek, 1991).

Salinization results from the buildup of dissolved solids in soil and soil water, and can occur in rainfed areas with inherently susceptible soils (as in parts of Australia) as well as in irrigated areas. UNEP considers that salinization is the second largest cause of land loss, but there are wide differences in the estimates of the area affected and of the area going out of production. Oldeman, Hakkeling and Sombroek (1991) estimate the total affected area to be over 76 million ha but do not differentiate between irrigated and rainfed areas. It seems possible that some 20 percent of the total irrigated area is affected and some 12 million ha of irrigated land may have gone out of production (Nelson and Mareida, 2001). The problem can be very serious at the subregional and national level. India, for example, has lost about 7 million ha (Umali, 1993; FAO/UNDP/UNEP, 1994; FAO, 1999b). In some semi-arid countries, 10 to 50 percent of the irrigated area is affected to a greater or lesser degree (Umali, 1993; FAO, 1997b, 1997e), with average yield decreases of 10 to 25 percent for many crops (FAO, 1993a; Umali, 1993). Unfortunately there are little or no time series data to allow reliable estimates of the rates of change in the salinized area. It could be 1-1.5 million ha p.a. and increasing (Umali, 1993) but it is difficult to quantify. Of particular concern are those irrigated areas in semi-arid regions that support large rural populations, such as the western Punjab and Indus valley where large areas of waterlogged saline land are spreading through the intensively irrigated plains.

Pollution by fertilizers. Since the 1970s extensive leaching of nitrate from soils into surface water and groundwater has become an issue in almost all industrial countries (OECD, 2001a). In large areas of the EU, for example, concentrations are near to or exceed the maximum permitted concentration of 50 mg per litre or 50 ppm (parts per million). This nitrate poses a risk to human health and contributes to eutrophication of rivers, lakes and coastal waters. The bulk comes from diffuse sources arising from mineral fertilizer and manure use on both crops and grasslands. The problem is now serious in parts of China and India and a number of other developing countries, and will get worse (Zhang *et al.*, 1996).

The problem occurs primarily when N application rates exceed crop nutrient uptake. The risk depends on crop type and yield, soil type and underlying rocks (Goulding, 2000). The risk of high nitrogen (and some phosphate) losses through leaching and runoff can become serious unless there is good fertilizer management (Hydro, 1995; MAFF, 1999). There are large regional and crop differences in fertilizer application rates per hectare (Daberkov *et al.*, 1999), and large spatial and temporal differences in nutrient levels and fertilizer-use efficiency on similar soil types. Hence the projected changes in average application rates given in Table 4.15 are not a good indicator of the risk of nitrate losses. In the United Kingdom, the present average application rate for all arable crops is about 150 kg N/ha, but the range is 25-275 kg N/ha with application rates of more than 150 kg on over 35 percent of arable land. In parts of China the situation is even more extreme with some rice farmers applying over 870 kg N/ha, almost four times the national average. As stated above, high application rates as such should not be a problem as long as crop yields are commensurate, but they become problematic when application rates exceed crop nutrient uptake. In contrast, most crop production in sub-Saharan Africa takes place without the benefit of mineral fertilizers and soil fertility remains very low or declining (Chapter 4).

Chapter 4 assumes substantial gains in fertilizer-use efficiency and hence a relatively modest aggregate growth rate in N fertilizer demand, projected to decline to less than 1 percent p.a. by 2030. However, extensive areas in both developed and developing countries already receive large nitrogen fertilizer applications that are not commensurate with the availability of adequate soil moisture, other nutrients and management practices needed to attain high yields. Even modest increases in nitrogen fertilizer application could cause problems when yield growth stagnates, leading to nutrient-use inefficiencies and severe pollution. Four difficulties arise here. First, these losses can occur at N application rates below the economic optimum, since current fertilizer prices do not include the cost of environmental externalities (Pretty *et al.*, 2001). Second, maximizing the efficiency of N use is complex and difficult (Goulding, 2000). Third, it may take many years for improvements in fertilizer-use efficiency to result in reductions in nitrate losses and decades for groundwaters to recover from nitrate contamination. Fourth, the situation could be particularly serious for the production of vegetables, because they are often grown in or close to urban areas so that there is fairly direct contamination of the drinking-water sources for large numbers of people.

Water pollution arising from agriculture has other dimensions. Nitrogen and phosphate enrichment of lakes, reservoirs and ponds can lead to eutrophication, resulting in high fish mortality and algae blooms. This is important because of the growing importance of aquaculture (Chapter 7). Algae blooms release toxins that are poisonous to fish and humans. The human risks are a growing problem in some developed countries and potentially even more serious in warmer developing countries with more intense sunshine (Gross, 1998).

Further intensification of fertilizer use may also add to the widespread problem of soil acidification (Scherr, 1999). A combination of improved nutrient management and liming could limit this but ammonia emissions from livestock and nitrogen fertilizers, discussed above, also add to soil acidification through acid rain. The conjunction is causing serious ecosystem damage in some developed countries, and this could also occur in developing countries, particularly in East Asia with the rise of industrial-scale pig and poultry production.

Pesticide pollution. Pesticide use has increased considerably over the past 35 years. Recent regional growth rates have ranged between 4.0 and 5.4 percent (Yudelman, Ratta and Nygaard, 1998). This has led to serious water pollution in OECD countries (OECD, 2001a). Pesticide pollution is now appearing in developing countries as well, exacerbated in some instances by the availability of cheap, out-of-patent, locally produced chemicals.

Future pesticide consumption is likely to grow more rapidly in developing countries than in developed ones (Morrod, 1995), although the introduction and spread of new pesticides may occur more rapidly in the latter. The environmental implications of this growth are difficult to assess. For example, application rates per hectare have gone down, but the new pesticides are biologically more active. Improved screening methods for pesticide safety and environmental health legislation have helped to reduce the mammalian toxicity of pesticides and to assess other potential environmental damage. On the other hand, the adoption of improved application techniques has not progressed sufficiently in the past decade, particularly in the case of sprayers, so that a high proportion of pesticide still fails to reach the target plant or organism (Backmann, 1997). This situation is unlikely to change in the near future.

Over the period to 2030 several factors could create significant breaks from recent trends in pesticide use, and could reduce pesticide contamination of groundwater and surface water, soil and food products. Developed countries are increasingly using taxes and regulatory measures to reduce pesticide use (DME, 1999; DETR, 1999). The rapid growth in demand for organically grown food will continue to reduce the use of pesticides. Research in "smart" pesticides using advances in biotechnology, knowledge of insect hormones and insight into the ecological basis of pest control, etc. is likely to result in safer control methods within the next decade or so (Thomas, 1998). There will be further development of IPM for crops other than rice, which should help to reduce the use of insecticides and, to a lesser extent, fungicides and herbicides (Yudelman, Ratta and Nygaard, 1998). However, shortages of farm labour, the reduced use of flood irrigation for rice and the spread of minimal tillage systems could lead to major increases in the use of herbicides and herbicide-resistant crops.

Pollution from livestock wastes. Water pollution also arises from intensive dairying and from the landless rearing of pigs and poultry, particularly in East Asia. Here peri-urban industrial-scale pig and poultry production has caused serious environmental damage, especially water pollution, unparalleled in the industrialized world (de Haan, Steinfeld and Blackburn, 1998). The problem arises from discharges or runoff of nitrogen and other nutrients into surface waters because of bad waste management and from environmental impacts of feed and fodder production (Hendy, Nolan and Leng, 1995; de Haan, Steinfeld and Blackburn, 1998). In the medium term these problems seem bound to increase, although the technological means of overcoming them are neither complex nor very costly.

12.3.4 Loss of biological and ecological diversity

In the main, recent land cover changes have reduced the spatial distribution of species rather than causing their extinction, although this has happened and will continue to happen on a more limited scale. The loss of wild relatives of crops and of native crop varieties that are better adapted to unfavourable or changing environmental conditions could be particularly serious for crop introduction or breeding programmes to adapt to climate change.

The projections of land cover and land use change do not explicitly examine changes in biodiversity,[4] but they do provide some proxy indicators. These can help in assessing how the impacts of agriculture on biodiversity might evolve over the projection period. The focus of this chapter is on the environmental and ecosystem impacts of the changes, rather than on plant genetic resource issues. Pressures on non-agricultural biodiversity from land clearance and the inappropriate use of agrochemicals may in future grow more slowly because of the increase in protected areas and land restoration.

However, there will be increasing pressures on biodiversity within agricultural production systems. This will stem primarily from the intensification of production. Together with economic forces, intensification will lead to farm and field consolidation; reduction of field margins; clearance and levelling of adjacent wastelands so that they can be cultivated; further expansion in the use of modern varieties; greater use of pesticides; and higher stocking rates for grazing animals. These trends can lead to the destruction of the habitats of beneficial insects and birds that help to keep crop pest populations under control, and to other losses in biodiversity. However, assessment of these losses in developing countries is severely limited by lack of data on quantitative and qualitative changes in pesticide use, livestock densities and wildlife populations.

The effects of agriculture on non-agricultural biodiversity can be positive as well as negative, depending upon the situation. In the United Kingdom, for example, the intensification of pastoral systems has been an important factor behind the decline in bird populations. On the other hand, in Norway around half of the threatened species depend on agricultural landscapes and therefore the conservation of biodiversity is closely related to the protection of such landscapes (Dånmark, 1998), including grazing systems that prevent pastures from reverting to scrub or woodland.

Nonetheless, intensification will have a major positive impact by reducing the need to convert new land to agriculture. CGIAR has estimated that land saved through yield gains over the past 30 years from CGIAR research on seven major crops is equivalent to 230-340 million ha of forest and grassland that would have been converted to cropland in the absence of these gains (Nelson and Mareida, 2001). Their estimate excludes the land savings that stemmed from research on other crops, from national and private research systems and from farmers' own research and development. Some estimates of land savings resulting from all past research efforts and agricultural intensification amount to more than 400 million ha (Goklany, 1999).

Agriculture's main impacts on wild biodiversity fall into four groups. First, there is the loss of natural wildlife habitat caused by the expansion of agriculture. This has been a major force in the past, and will continue in the future, although much more slowly. The projections of Chapter 4 suggest that an additional 120 million ha of arable land will be required over the next 30 years. Inevitably these will involve a reduction in the area of natural forests, wetlands and so on, with attendant loss of species.

Second, there is the general decline in species richness in managed forests, pastures and field margins, and the reduction of wild genetic

[4] Biodiversity includes genetic differences within each species, diversity of species and variety of ecosystems.

resources related to domesticated crops and livestock. There are comprehensive and well-maintained *ex situ* germplasm stocks for the major crops, and gene transfer and other advanced plant breeding tools have opened up new possibilities for genetic improvement. Nevertheless, these losses in the wild could be serious for future crop and livestock breeding. They cannot be quantified at present, although advances in molecular biology may provide the tools needed for more robust monitoring.

Third, there is the reduction of wild species, including micro-organisms, which help to sustain food and agricultural production, for example through soil nutrient recycling, pest control and pollination of flowering crops. This can be regarded as damage to the life support system for agriculture, given the vital role some of these species play in soil fertility maintenance through nitrogen and carbon cycling. Such losses are of increasing importance with the shift to integrated farming and the growing emphasis on IPM. The intensive use of mineral fertilizers is known to change soil microbe populations (Paoletti, 1997), but does not appear to disrupt nutrient recycling. Intensive grazing lowers plant species richness in pastures but the long-term consequences of this are not known. In developed countries, loss of insect-eating bird species, as a result of reduction or removal of field margins or pesticide use, has been firmly linked with increases in crop pest damage. This problem may arise increasingly in developing countries.

Lastly, there is the reduction in wild species that depend for habitat, food, etc. on agriculture and the landscapes it maintains – the habitats, flora and fauna that would not exist without agriculture. Richly diverse chalk grasslands, for example, would revert to scrub or woodland without grazing pressures, with the loss of ground-nesting bird species, butterflies and herbaceous plants. The reduction of wild species is most apparent in those EU countries that have lost large areas of hedges, ditches, shrubs and trees through field and farm consolidation. Losses have also arisen from extensive use of insecticide and herbicide sprays with consequent spray drift on to field margins and other adjacent ecological niches. Increased stocking rates on extensive pastoral systems have led to a decline in birds that either nest on such land or are predators of rodents, etc. living on these lands.

The impact of livestock production on biodiversity takes two main forms: high grazing pressures and reseeding of pastures. Grazing pressures are likely to rise with time in some areas, particularly where marketing infrastructure is weak and there are few alternative livelihoods, even though there is a continuing shift to limited or zero grazing such as feedlots and stall-feeding systems. In other areas, however, the area of grazing land and pastures will probably decline as the more marginal areas are abandoned. Some pastures will be converted into cropland and urban and industrial land. Such land use changes can be appreciable. In western Europe, for example, the area of meadows and pastures declined by 10 percent between 1970 and 1988 (OECD, 1991). This decline was associated with the rise in stocking rates. On rough pastures these commonly increased by 50 to 100 percent between 1970 and 1990 (Pain, Hill and McCracken, 1997) and they have risen even more on improved pastures. Such increases in stocking rates have been linked to the loss of certain bird species from large areas of the United Kingdom and Europe and lower populations elsewhere (Pain and Pienkowski, 1996). Similar stocking rate increases are projected for parts of sub-Saharan Africa and Asia, so they are also likely to suffer losses in bird and other wildlife populations. It is also likely that there will be a shift to more intensive pasture systems. This will most probably involve some reseeding of natural meadows, and hence loss of native grassland plants. Intensification of pastures normally also involves the application of high levels of organic or mineral fertilizers, leading to nitrate or phosphate loss to water systems. The experience of the developed countries indicates that these impacts can be substantial.

12.3.5 Perturbation of global biogeochemical cycles

Agriculture plays a significant role in the anthropogenic perturbation of several biogeochemical cycles, notably the nitrogen, phosphate and sulphur cycles. In the nitrogen (N) cycle, ammonia and nitrous oxide emissions from agriculture are significant, but there is also perturbation of N fixation. The manufacture of nitrogenous fertilizers, burning of fossil fuels and cultivation of leguminous crops have resulted in anthropogenic N fixation exceeding natural N fixation since about 1980, by an increasing margin. Some analysts suggest that "over the next few decades this alteration (of the N fixation cycle) will undoubtedly become even more severe" (Walker and Steffen, 1999), for example, if the use of nitrogen fertilizer more than doubles between 1990 and 2050, thereby causing a pro rata increase in direct and indirect N_2O emissions (Smith, 1999). However, the projections of N fertilizer use and leguminous crop cultivation given in Chapter 4 and of manure production discussed earlier in this chapter all point to a slowing down in the growth of agriculture's contribution to this perturbation. Moreover, there are a number of other changes, e.g. in land use management, which should also reduce perturbations of the N cycle. For example, the expected increase in the area under NT/CA and other measures to counter soil erosion should reduce the loss of nitrogen in eroded organic matter from arable land. But in contrast, other land management practices such as burning may result in increased nitrogen losses, particularly if climate change results in increased summer maximum temperatures and greater fire risk in savannah and other fire-prone ecosystems (Lavorel *et al.*, 2001).

12.4 Current and emerging solutions

It is clear from Section 12.3 that some of the most serious environmental pressures stem from agricultural intensification. This process started in the developed countries over 50 years ago and some of the environmental problems became clear in the 1960s (Alexandratos, 1988). A number of them have been overcome while others remain and seem likely to grow in severity for the next decade or so (OECD, 2001a). The policy and technological successes and failures of developed countries can be of great help to those developing countries that are now suffering the environmental damages of intensification. They may even help those countries and farmers who have yet to intensify production to avoid some of the environmental problems that could arise. Many of the required policy, regulatory and technological actions are known. If pursued, such actions could result in a more favourable agro-environmental future than that outlined in the preceding section.

Reduction of pollution by fertilizer. The EU and North America have used a number of research and regulatory measures to limit pollution from fertilizers, such as research on slow release and other less polluting formulations; tighter emission and discharge standards for fertilizer factories and higher fines; public and private advisory (extension) services; physical limits on the use of manure and mineral fertilizers; and application of the nutrient budget approach.

These actions have not been enough to prevent serious buildup of nitrate in drinking-water sources and the eutrophication of rivers, lakes and estuaries (OECD, 2001a, 2001b; EEA, 2001). Since the early 1990s an increasing number of countries have been introducing economic measures in the form of pollution taxes on mineral fertilizers.

All of these actions are or will be relevant to developing countries. They can be formulated in the framework of a strategy for integrated plant nutrition (see Chapter 11). Some countries will have to remove a number of other distortions, such as direct and indirect subsidies to mineral fertilizer production or sales (e.g. energy subsidies to nitrogen fertilizer). They will also need to phase out low-efficiency fertilizers such as ammonium carbonate, and provide adequate funding to extension services so that they are not even partially dependent on the sale of fertilizer.

The consumer-led drive towards organic agriculture will limit fertilizer pollution in some areas, as will the adoption of NT/CA over a much larger area.

Reducing pesticide pollution. A number of important lessons can be drawn from past experience. First, rigorous testing procedures must be in place to determine the safety of pesticides before they are allowed on the market. The developed countries have suffered in the past from weaknesses in this regard, and have had to tighten their procedures. It is important that pesticide safety information is shared with developing countries through the International Plant Protection Convention (IPPC) and other mechanisms. In addition, as more developing countries become pesticide producers and develop their own products, it is essential that they implement their own testing, licensing and control procedures.

Second, even where the above measures are in place, environmental problems can arise from the accumulation of pesticide residues along the food chain, in soils and in water, e.g. the buildup of atrazine in water supplies in Europe and the United States. There must be comprehensive and precise monitoring systems to give early warning of residue buildup. The international sharing of information, e.g. through the Codex Alimentarius, provides valuable support to developing countries that lack adequate monitoring and testing facilities. Moreover, in the context of consumer safety and the WTO agreements, rigorous procedures must be in place to ensure food safety and enable agricultural exports.

Third, pest control measures should be implemented in a strategic framework for IPM (Chapter 11), which aims to avoid or minimize the use of pesticides. In recent years a number of developed countries have concluded that even with the above measures some farmers are still applying too much pesticide, or pesticide accumulation in the environment has not been reduced. They have decided, therefore, to use economic as well as regulatory measures, and to impose pollution taxes on pesticides so as to create economic incentives to reduce their use. Such taxes appear to be a valid option for a wider range of countries and situations, although it may be some time before many developing countries have the institutional capacity to implement them.

Development and expansion of no-till/conservation agriculture. The biological, environmental and economic advantages of NT/CA have been described in Chapter 11. The wider adoption of NT/CA depends on raising awareness among politicians and farmers of the benefits of conservation agriculture. Government policies need to be directed towards creating the appropriate conditions for its uptake. Farmers need to see how it meets their specific needs. The lessons learned from the farmer-to-farmer training approach used successfully for IPM in Asia could be of help. For example, Brazilian farmers who have benefited greatly from NT/CA could share their experience with farmers in Africa and help them to adapt the technique to their own conditions. Greater national research and development efforts and international assistance will be needed to develop the technique for other agricultural environments and production systems.

Improving water management. Water scarcity and intersectoral competition for water are major problems. Reduced groundwater recharge because of deforestation and soil degradation is also an important issue. The most serious direct environmental problem is salinization. Three main actions could be used to limit salinization: (i) greater investment in better drainage and distribution canals, even though planners have been slow to act on this option in the past; (ii) better water management, for example through the increasing involvement of farmers in water users' associations and similar bodies; and (iii) stronger economic incentives for water conservation, which are growing as governments increasingly implement water-pricing policies and as competition from other sectors drives up the price.

Promotion of organic farming. While the technological approaches described above are measures to reduce the negative effects of conventional agriculture on the environment, organic agriculture (for environmental reasons) does not use any industrial fertilizer or pesticide inputs at all. The use of such inputs commonly has negative effects on the environment; however, their non-use does not necessarily make agricultural production sustainable. Soil mining and erosion, for example, can be problems in organic agriculture. Organic farming can also cause serious air and water pollution – for example, the overuse of manure or badly managed applications can increase ammonia in the air and nitrate in groundwater.

The rapid expansion of organic production during the past decade has already made an appreciable contribution to pollution reduction and agricultural sustainability in Europe (FAO/COAG, 1999). Three aspects need to be clarified. First, badly managed organic agriculture can result in some of the same pollution problems that arise from conventional agriculture, but not in others such as those associated with the use of industrial inputs and production systems described in the preceding sections. Second, although the rate of expansion has been fast, the proportion of agricultural land involved is small. Current policies in many EU countries aim at a considerable increase in the agricultural land under organic farming (see Chapter 11). Third, most of the pressure for the switch to organic farming is in the developed countries (FAO/COAG, 1999).

The environmental and economic benefits of organic farming can be increased in a number of ways. These include introduction of policies that bring prices of industrial inputs in line with their full economic costs, including externalities; improvements in product standards, certification and labelling to give consumers confidence that they are buying genuine organic foods (FAO, 1999f); establishment of an internationally agreed accreditation mechanism, particularly procedures to gain international equivalence of organic product standards; greater government assistance to farmers wishing to switch to organic farming; regulations to enforce or encourage the use of organic farming as a means of overcoming or reducing problems such as the buildup of nitrate in groundwater; increased research to widen the range of organic agricultural techniques; improvements in the availability of or access to organic inputs, e.g. GMO-free seed, rock phosphate and manure; and capacity building in extension systems, farmers' cooperatives and national accreditation bodies to remove barriers to the expansion of organic farming, particularly in extension services that still promote approaches centred on the intensive use of mineral fertilizers and pesticides.

Improving livestock waste management. The main actions required here are the following. Development of national strategies for livestock waste management to provide the general framework for local action; improved policy and regulatory framework, with clearly defined and enforceable discharge and emission standards and effective waste disposal charges; meaningful penalties for breaches in regulations, and an expanded range of economic instruments to discourage poor livestock waste management, e.g. pollution taxes to limit waste discharges from livestock farms and fisheries; well-targeted programmes to disseminate best practices; strengthened guidelines to optimize the location of livestock production units and to prohibit the development of certain types of intensive livestock units in unsuitable areas; increased support for the adoption and dissemination of appropriate technological measures, with emphasis on introducing better techniques for livestock waste management already available in developed countries; drawing lessons from North America and the EU on the failure of regulatory approaches alone to achieve adequate livestock waste management; and improved donor coordination and environmental impact assessment (EIA) to ensure that international projects have adequate provision for sound livestock waste management.

12.5 Physical and economic trade-offs

Earlier sections have shown that agriculture is an industry with substantial environmental consequences upstream and downstream as well as onfarm. It is evident that crop production and food security cannot be achieved at zero environmental cost. The issue therefore is whether environmental costs can be minimized so that future food security is not at risk.

The trade-offs involved are multidimensional. They vary over time and space, between different environmental goods and services, and between different developmental goals. It is for society to decide which trade-offs are acceptable and which ones can be mimimized, but this raises the question of whose society, and who in society should decide. A few examples of the various types of trade-offs are mentioned below.

Between countries and regions. The increasing switch in developing countries to intensive, grain-fed livestock production systems close to urban markets has reduced or prevented overgrazing of rangeland. But it has transferred part of the environmental burden to developed country exporters of feedgrains, because row crops such as maize are more susceptible to soil erosion and nitrate leaching (although improvements in farming practices have been reducing this damage in recent years). The past high rates of growth for dairy, pigs and poultry in some major developing countries were only possible through the use of large quantities of feed concentrates imported from North America and other developed countries.

Spatially within countries. This expansion of intensive livestock production has also led to a number of environmental trade-offs within countries. First, it tends to shift the environmental burden from non-point to point pollution, with greater discharges of concentrated liquid and solid wastes, causing serious water pollution. Second, it reduces the grazing pressures on vulnerable semi-arid pastures and steep slopes, but it separates arable and livestock production. This limits or prevents the return of livestock manure to cropland, which is often vital in raising crop yields and maintaining soil fertility. Hence some countries, notably the Netherlands, have introduced regulations on stocking rates or manure recycling. Moreover, the production of large quantities of feedgrain and fodder crops can lead to serious soil erosion, and to environmental problems stemming from fertilizer and pesticide use. The higher stocking rates of intensive systems lead to loss of biodiversity from trampling and reseeding (Pain, Hill and McCracken, 1997), and more concentrated emissions from manure and urine, causing ecosystem acidification locally and GHG accumulation globally (Bouwman *et al.*, 1997).

Over time within countries. The European experience shows how forest clearance for food production can buy time while technology and international trade catch up with population growth, allowing marginal cropland eventually to be reforested (Norse, 1988). Most European countries converted forests to cropland prior to the application of mineral fertilizers and modern crop breeding techniques. However, the loss of biodiversity from such deforestation may be permanent, and it may be impossible to re-establish the original forest ecosystem.

Over space and time. Erosion from steep slopes that are difficult to cultivate and inherently unstable is commonly followed by the redeposition of sediments in reservoirs, in river valleys and estuaries up to 1 000 km or more away. The result with time is the creation of flat lands that are easy to cultivate. In South and East Asia such lands have been able to sustain crop production for thousands of years. On the other hand, by reducing the storage capacity of drainage systems this erosion can contribute to severe flooding, loss of human life and serious economic losses (FAO, 1999g), and it may be impossible to restore eroded slopes to their original vegetation.

Between food security and the environment. Poor farmers in various parts of the world are mining soil nutrients because they lack access to sufficient organic manure or mineral fertilizer (Bremen, Groot and van Keulen, 2001). They know that their land use practices cause environmental damage that may ultimately endanger future food security but immediate food needs take priority (Mortimore and Adams, 2001).

Greater intensification of cropland use versus greater loss of biodiversity and GHG emissions from deforestation. The introduction of new technologies that lead to higher yields or returns on existing land reduces the need for further land development. This can save a considerable amount of forest and rangeland (Nelson and Mareida, 2001) and eventually allow marginal cropland to be taken out of production and used for more sustainable systems, e.g. agroforestry, forestry, pastures and recreation. However, even under well-managed sustainable systems such as IPNS and IPM, intensification can lead to more fertilizer and pesticide pollution (Goulding, 2000), greater GHG emissions from nitrogen fertilizer and loss of biodiversity on intensively grazed pastures.

Reduction of soil erosion and water pollution versus greater pesticide use. NT/CA, minimum tillage and related approaches to land management have multiple environmental and farm income benefits, yet may require greater use of herbicides. However, initial fears that NT/CA would lead to greater use of herbicides have not been fully confirmed, as herbicide use can be reduced or eliminated in systems following all the principles of NT/CA, once a new agro-ecosystem equilibrium has been established. Using green cover crops to reduce nitrate leaching during the autumn and winter may increase carry-over of weeds, pests and diseases and lead to greater pesticide use.

The potential environmental benefits versus risks of GM crops. As discussed in Chapter 11, GM crops can have a number of environmental benefits such as (i) reduced need for pesticides, particularly insecticides (e.g. Bt maize and cotton) and herbicides (e.g. Ht soybeans), although these gains are not necessarily permanent as pests can overcome the resistance of GM crops; (ii) lower pressures for cropland development and deforestation because of higher yields from existing land; and (iii) increased opportunities to take marginal land out of production for set-aside or to cultivate some crops less intensively. The technologies involved can produce cultivars that can tolerate saline soils and thereby help to reclaim degraded land. On the other hand, there are a number of possible environmental impacts and risks, such as the overuse of herbicides with herbicide-tolerant varieties and accumulation of herbicides in drinking-water sources; herbicide drift from cropped areas, killing plants in field margins, and hence leading to the death of insects and birds in or dependent on field margins; death of beneficial insects feeding on GM crops; and crossing of GM crops with wild relatives and particularly with related weed species, e.g. red rice, possibly leading to the development of herbicide-resistant weeds.

The most vocal concerns about agricultural pollution and ecosystem damage tend to come from environmentalists in developed countries. But in a number of respects an improved environment is a luxury good that these countries can now afford. In earlier times they had different priorities (Alexandratos, 1995). Until the 1960s, when most people were concerned with improving their incomes, diversifying their diets and general welfare, protection of the environment was a low priority for all but a small minority (Reich, 1970; Nicholson, 1976), and some serious environmental problems arose. Since then income growth, education and better understanding of the environmental consequences of different agricultural practices and lifestyles have led to a growing consensus that governments should do more to protect the environment and that the public should pay more for environmental protection and food safety.

Industrial countries have the economic and technical capacity to introduce additional measures to protect the environment, and can afford the higher food costs that may follow as a consequence of these actions. In short, they are more able to pay for trade-offs between environment and development, although current actions seem unlikely to prevent some growth in agricultural pollution over the next 20 years or so (OECD, 2001a).

Environmentalists and government officials in developing countries are no less aware of the negative environmental consequences of agricultural growth. However, their responses are constrained by inadequate finance for the necessary research, particularly in sub-Saharan Africa; lack of institutions and support services that could raise awareness of potential ways to minimize or eliminate trade-offs; and the need to avoid measures that raise food prices because a high proportion of people are unable to buy adequate food even at current prices.

12.6 Concluding remarks

It has been argued that during the next decades environmental trade-offs will be more difficult than in the last few decades, with fewer win-win situations and more obvious losers than winners (OECD, 2001a). This is not necessarily the case for agriculture in many developing countries if market signals are corrected so that they include the value of environmental goods, services and costs; give farmers everywhere the incentive to produce in a sustainable way; overcome the negative impacts of intensive production technologies; give resource-poor farmers the support they need to react to environmental and market signals (Mortimore and Adams, 2001); and North and South work together to remove production and trade distortions (McCalla, 2001).

There are many opportunities for placing agriculture on a more sustainable path over the next decades, with benefits for both farmers and consumers. For example, measures resulting in higher nitrogen fertilizer-use efficiency and IPM reduce production costs for the farmer and provide safer food, and at the same time they are cheaper than drinking-water treatment in reducing nitrate and pesticide residues.

Future agro-environmental impacts will be shaped primarily by two countervailing forces. Environmental pressures will tend to rise as a result of the continuing increase in demand for food and agricultural products, mainly caused by population and income growth. They will tend to be reduced by technological change and institutional responses to environmental degradation caused by agriculture. The early implementation of available policy and technological responses could reduce negative agro-environmental impacts or slow their growth, and speed up the growth of positive impacts.

Agricultural intensification is required for food security and for the conservation of tropical forests and wetlands. The main priority is to decouple intensification from the environmental degradation caused by some current approaches to intensification, by reshaping institutional structures and market signals. Research and farming practices must also be redirected towards greater use of biological and ecological approaches to nutrient recycling, pest management and land husbandry (including soil and water conservation).

This decoupling has already started in some countries, but it will take time before it has appreciable effects. Hence agro-environmental impacts in the nearer future will be largely a continuation or acceleration of present trends. In particular, there will be a further slowdown in deforestation and rangeland clearance for crop production. Thus the main quantitative impacts on the environment will stem from the intensification of production on existing cropland, rather than from expansion of cropland. There will be increasing pressure on some marginal lands, but progress in research and better off-farm employment opportunities seem likely to lead to the abandonment and natural recovery of some marginal lands in Asia and Latin America. There will also be moderate increases in the area under irrigation. Drainage development and better irrigation water management will help to limit or reduce soil damage from waterlogging and salinization. Lastly, increased intensification of production on existing arable land will have two main characteristics. There will be enhanced use of precision farming and other advanced technologies, for example sophisticated plant breeding and controlled release of mineral fertilizers. And the growth of fertilizer and pesticide use will slow down because of regulatory measures and consumer demand for organically grown produce.

The focus of concern is likely to shift from the onfarm impacts of physical land degradation towards chemical and biological impacts, and from onsite towards offsite and downstream impacts of air and water pollution. Soil erosion may be reduced in important crop production areas by the projected shifts in technology. However, air and water pollution from mineral fertilizers and intensive livestock production will increase, with more widespread nitrate contamination of water resources, eutrophication of surface waters and ammonia damage to ecosystems.

The slowing down of deforestation will reduce the rate of loss of biodiversity, but the intensification of cropland and pasture use seems likely to increase such losses. The general picture for desertification is less certain, but the abandonment or reduced use of extensive semi-arid grazing lands should lower the risk of desertification.

The overall pattern of future agro-environmental impacts is one of trade-offs between increased agricultural production and reduced pressures on the environment. Intensification of crop production on existing cropland reduces the pressure to deforest, but tends to increase water pollution by fertilizers and pesticides. Similarly, the switch from extensive to intensive livestock lowers grazing damage to rangelands but, for example, may increase water pollution from poorly managed manure storage.

On the other hand, intensification of production on the better lands allows the abandonment of erosion-prone marginal lands, and improvements in fertilizer-use efficiency and IPM together with the expansion of organic farming are projected to slow down the growth in use of mineral fertilizers and pesticides. Similarly, the concentration of livestock into feedlots or stalls makes it more feasible to collect and recycle manure and to use advanced systems for water purification and biogas production.

In an increasing number of situations the trade-offs are becoming less serious. Thus, for example, NT/CA may reduce overall pesticide use; reduce soil erosion, fossil energy inputs and drought vulnerability; and raise carbon sequestration, natural soil nutrient recycling and farm incomes. Factors such as these lead to the overall conclusion that agro-environmental impacts need not be a barrier to the projected production path because they can be reduced considerably through the adoption of proven policies and technologies.

It is one thing to project the potential for a reversal or slowdown in the growth of agriculture's negative impacts on the environment. It is quite another matter to make such a future a reality. This will need a multidimensional approach and the integration of environmental concerns into all aspects of agricultural policy. Such actions were first proposed more than a decade ago (FAO, 1988) but are only now being pursued in a partial manner by some developed countries. Governments need to exploit the complementary roles of regulatory, economic and technological measures. Actions are needed at the global, regional, national and local level. None of these actions will be easy, but the real achievements of some countries and local communities over the past 30 years in promoting sustainable agricultural development show what could be achieved over the next 30 years, given more coherent efforts.