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The environmental implications of intensified land use in developing countries

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SUMMARY

The major agricultural intensifications in the developed world over the last half century have produced a range of important environmental problems. These include pollution, damage to wildlife and landscape and other issues, both on- and off-site. These are largely being controlled by scientific investigation and Government regulation. As developing countries increase agricultural production over the next 30 years, this may also cause even more serious environmental damage.

The paper distinguishes between production-related on-site damage, and off-site and more extensive effects. Both may involve soil and water effects, such as soil erosion, salinization, siltation, eutrophication and loss of water quality. The use of more agrochemicals can damage water quality, health, wildlife and biodiversity. Loss of habitat from the extension of farming is particularly damaging to biodiversity. A developing off-site problem is the production of greenhouse gases by farming systems, including the conversion of forests to farmland. In the future the introduction of genetically engineered species of plants, animals or microbes will need secure control.

Much work, probably on a catchment basis, is necessary to understand and control these problems. The three main requirements are much better environmental information from the developing world; the selection of environmental indicators to be monitored; and the support of local farmers in protecting the environment. There are encouraging indications of farmer concern and action over obvious on-site damage, but this may not extend to extensive off-site issues. The main danger is that a developing food scarcity would cause the environmental issues to be ignored in a race for production.

1. INTRODUCTION

Environmental issues form a confusing and often illogical collection that are difficult to classify. They can be regarded as global, regional or local, of which the only truly global issues result from alterations to the atmosphere or ocean. However, some very important issues are local in origin, but occur so frequently that they are considered to be global. Because of its global spread, agriculture is concerned with most of such issues (figure 1). These effects have occurred so widely in intensive developed agriculture, that intensive agriculture is now often regarded as damaging to the environment on a global scale.

If the Malthusian precipice is to be avoided, agriculture has to become more productive per unit area (intensification of agriculture) or it has to use larger areas of land. The latter is often difficult or impossible (Buringh & Dudal 1987). The only viable alternative is intensification of agriculture, based on greater chemical, physical and biological inputs, which may cause damage to the environment.

2. WHAT IS ENVIRONMENTAL DAMAGE?

Issues that are normally agreed to be 'environmental' (figure 1) may affect production, resources and/or the general environment. It is therefore desirable to discuss all these issues in the context of sustainability. In a general sense, sustainability requires that this generation shall pass on to the next at least as much capital as it inherited (Serageldin 1996), including 'natural capital'. Environmental issues are connected with damage to this natural capital.

A more functional definition of sustainability (Tinker 1988) can be useful in analysing the position of agriculture. To be sustainable, a process must (i) be economically viable; (ii) not destroy the resources on which it depends; and (iii) not physically damage the interests of others.

In the first group, some 'environmental' issues have immediate economic implications, such as the effect of soil degradation. The second group includes issues of longer-term resource conservation, such as the use of ground water. Crosson & Anderson (1992, 1995) argue that both of these groups should be related to production rather than to the environment alone. The third group brings in issues that have no direct costs to the farmer; this therefore includes all off-site effects. In this paper I use the word 'environmental' mainly in the rather specific sense of the processes that have no direct economic impact on the farmer who causes them; the costs are therefore 'externalized' (Crosson & Anderson 1992). However, all these problems must be dealt with before agriculture can be said to be fully sustainable.

Using this definition health problems must also be included. This includes 'environmental' health issues,

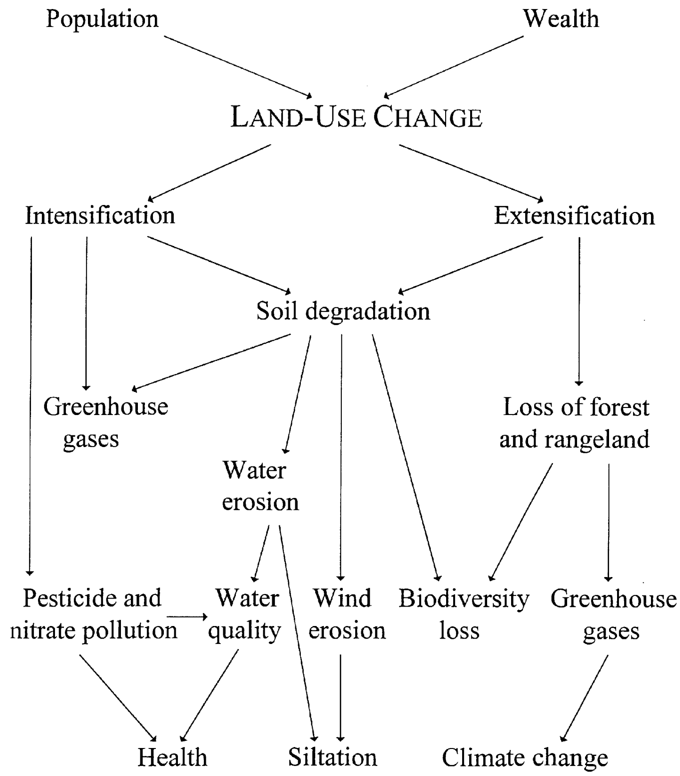

Figure 1. Interconnections between environmental impacts and original causes.

and the health damage caused by accidents during the use of agricultural chemicals or processes. There is no space to discuss either in detail in this paper.

There is a continuing need for more practical criteria in the concept of agricultural sustainability. As Biswas (1995) asks, 'How do we know when our agriculture has stopped being sustainable?' Faeth (1993) and many others have developed systems for natural resource accounting, and this is not too difficult to do in relation to the production-related on-site effects. Costing the various off-site effects is more complicated. The costs due to siltation of a dam may be calculated fairly precisely, but not for the emissions of greenhouse gases or for loss of biodiversity, so that assessing these is very subjective. Changes that are irreversible or only reversible with great difficulty should always be prevented wherever this is possible.

'Environmental' issues therefore arise from a wide mixture of motives, ranging from economic self-interest, through consideration for future resources, to purely ethical considerations. It is not surprising that arguments are often confused and agreement difficult to reach.

3. THE EXPERIENCE OF DEVELOPED AGRICULTURE

Environmental problems are relatively recent even in developed agriculture (World Bank 1995), because the modern technologies were only applied fully after the Second World War. Apart from the soil damage in the American Midwest in the 1930s, environmental concern only developed widely after about 1960 (Carson 1962). Since then complaints against the intensive farmer in developed countries have increased rapidly (Tinker 1990, 1993). As a response, many variants of sustainable farming have been suggested in the developed world, but none has yet been generally accepted as being as productive as intensive farming, but without causing its environmental problems.

Experience from developed temperate farming cannot be transferred directly to the tropics, yet it may be helpful. The central question now is whether intensification of agriculture in the developing world can avoid the mistakes that were made during the intensification of agriculture in the developed world. The developing world must intensify without causing serious environmental damage, when the demand for food may seem an absolute priority, and the environmental damage may appear secondary. This need has not yet been perceived, thus Yunlong & Smit (1994) discuss sustainability in Chinese agriculture solely in terms of productivity and resources, i.e. the first two groups of processes defined above.

4. LAND USE CHANGE AND THE LOSS OF FORESTS

(*a*) *Land use change*

Only a fraction of the world's land is suitable for agriculture, and only a fraction of this is still unused (Buringh & Dudal 1987; Fischer & Heilig 1997). Much of the best of this potentially available land is at present under forest, and there is growing alarm about the rate of loss of forest (Myers 1992; Houghton 1994; Williams 1994). The felling and burning of forests releases the greenhouse gas carbon dioxide from the vegetation and the soil, and also destroys the habitat of

Table 1. *Extent and annual percentage loss of tropical forest, by type, for 1981–1990 and for the whole world* (*after World Resources Institute 1994*)

	rain forest	moist deciduous	montane	dry deciduous	dry and desert
extent 1990 Mha	714	592	201	179	68
loss per year %	0.6	0.9	1.1	0.9	0.5

species. Finally, there is a strong aesthetic interest in tropical forests. Objections to the use of savannah land are fewer, and large areas of savannah grassland may be appropriate for agricultural use (Smith *et al.* 1994).

However, there is an underlying conflict over what any remaining 'unused' land should be used for. Ecologists are insisting that forests must be retained for biodiversity conservation; energy and global change scientists want existing agricultural land to be turned over to forest, for sequestering carbon or producing biomass; meanwhile the agricultural community is calculating how much extra land is needed to ensure food security. Some synthesis between these demands is needed, even though land-use planning on a global scale may appear an impossible aim. The IMAGE.2 global change model (Alcamo 1994) provides a very useful synthesis of this type. It contains land use, agriculture and climate change submodels, the agricultural demand is driven by increases in population and wealth, and it is therefore possible to consider the global land use changes that flow from food demand. The output of this model suggests considerable losses of African forest in the next century (Alcamo 1994, p. 57).

(*b*) *The current state of tropical forests*

At present tropical forests cover some 6–7 % of the world land surface (World Resources Institute 1994). Estimates of the loss of forest have caused much argument because of differences in terminology and methodology (National Research Council 1993; Williams 1994; Bruenig 1996; Grainger 1996). Some authors have taken burning of any area as evidence of its permanent deforestation, but it is more important to determine what happens afterwards (Tinker *et al.* 1996). The traditional shifting cultivation of low or moderate intensity (Nye & Greenland 1960) allows secondary forest to regrow, whereas 'deforestation' should mean a long-term change in land use. The Food and Agriculture Organization's assessment of tropical forests indicated that 0.8 % (14 million ha) per year out of a total of 1756 million ha of all tropical forest cover was lost in 1980–90 (World Resources Institute 1994). Surprisingly the annual loss of true rain forest was only 0.6 % per annum, whereas the loss of montane forest was 1.1 %; the consequences of this for soil erosion are obvious (table 1).

According to Myers (1992), the annual loss of moist tropical forest for logging is 30000 km^2, for cattle ranching 15000 km^2, and for plantations, mining, etc. 10000 km^2. Some 87000 km^2 is used by small farmers, giving a total of 142000 km^2. Myers (1992) suggests that the annual rate of loss may be 240000 km^2 by the year 2000, by when the annual loss will be 4 % of the remaining forest. A rational response to the logging of tropical forest is to establish plantations of economic species, but at present plantations cover only 43.8 million ha (World Resources Institute 1994).

Originally Zaire had about 1 million km^2 of forest, and so far this has not changed greatly. However, as Africa is likely to have the largest population increase and the lowest gross national product per capita in the next century, this area is likely to decrease proportionately more than any other. The South-East Asian tropical forest is being felled at a comparatively high rate of 1.3 % per annum (World Resources Institute 1994), and Myers (1992) considers that it will be largely lost by 2030.

5. BIODIVERSITY LOSS

Many ecologists argue that the stability or productivity of ecosystems is maintained by high biodiversity. However, some very productive and stable ecosystems have low diversity, e.g. coniferous forests, and the question is not yet settled (Mooney 1996). Other arguments for conserving biodiversity are the possibility of obtaining valuable products or genes from hitherto unused organisms, and the ethical belief that we should not render any organism extinct. The strongest general argument is that extinctions are irreversible environmental changes, and should therefore be resisted on the precautionary principle.

There may be between 5 and 30 million species in the world (May 1992), of which only about 1.4 million have been identified (Harper & Hawksworth 1994). It is impossible to determine how many extinctions are occurring, because the total number of species is unknown, but if present global trends in loss of habitat continue, the number of extinctions must become very large. At the present time about 12 % of mammals and 11 % of birds are considered to be threatened (World Conservation and Monitoring Centre 1992), mainly by habitat destruction (World Bank 1995).

Tropical forests are extremely species-rich (Whitmore & Sayers 1992), both in plants and animals, so that discoveries of large numbers of previously unknown insect species in the canopies of rainforest trees caused a large increase in the total world estimate of species (Erwin 1988). The International Union for Conservation of Nature and Natural Resources (1989) has stated that 'conserving biological diversity equals conserving ecosystems', but tropical forests are regarded as 'fragile' ecosystems (Nilsson & Grelsson 1995), which explains the present concern over the conservation of tropical forest biota. Conservation in the environment is also essential for microbes (Bull

1991), which again argues for the need to maintain all major ecosystems. The priorities in conservation, identification and monitoring need to be identified more sharply (Tinker 1996), because large numbers of existing protected areas are likely to be inappropriate for their intended purposes by 2050, due to a combination of land use and climate change (Alcamo & Kreileman 1966).

Fragmentation with loss of habitat causes most loss of diversity (Newton 1995; Turner 1996). Loss of habitat accounts for 36% of extinctions, the other main causes being hunting 23% and species introductions 39% (World Conservation and Monitoring Centre 1992; Mooney 1996). Settlement for agriculture is therefore the main cause of extinctions, because fragmentation, habitat loss, introductions and hunting all follow from this. Conservationists therefore often see farmers as the enemy, but sometimes a combination of agricultural activity and conservation seems to work well (Halffter 1996; Miller 1996). The innovative use of agroforestry to shield forest reserves offers considerable scope (Gajasenji *et al*. 1996). The combination of landscape use and management with conservation (Szaro & Johnston 1996) should be strongly supported by agriculturalists.

It is difficult to protect biodiversity (McNeely 1996) because those most in favour of conservation are in towns in the developed world, whereas those who pay the price are in the rural parts of developing countries. However, some biodiversity loss affects agriculture directly. The breeding programmes for crop plants become more difficult as related species, land races and local breeds are lost (Evans 1977), as farmers move to the use of small numbers of high-yielding cultivars in centres of biodiversity (Lefort & Chauvet 1996). In this case resource and biodiversity protection support each other.

6. ON-SITE ENVIRONMENTAL DAMAGE IN AGRICULTURE

(*a*) *Socioeconomic conditions*

Most on-site damage and associated economic loss caused by farming will be evident to the farmer. In that sense, 'the polluter loses' directly, and it is to his or her advantage if 'the polluter pays' by correcting the problem. According to the definitions above, on-site damage is therefore more of a resource and economics problem than a strictly environmental one, though the off-site consequences are often important (Lal 1997).

On-site environmental damage often depends greatly upon the socio-economic conditions governing the use of the land. Thus large range lands (Menke & Bradford 1992) may be 'open range', so that all have access without limit, or 'commons' held by a particular group, or be individually owned (Anderson & Thampapillai 1990). In the first case overgrazing is almost unavoidable, and there are many examples of this (Hardin & Baden 1977) that finally leads to 'desertification', which is the permanent damage to soil under arid or semi-arid conditions caused by human action. For the second, local regulations may prevent damage, unless population growth and animal numbers increase so far that overgrazing occurs. If overgrazing can be avoided, the use of ranges for local large fauna can usefully combine conservation and development (Dasmann *et al*. 1973).

Table 2. *Inputs including agrochemical use in selected countries 1989–1990* (*after World Resources Institute 1994*)

country	farmed total area Mha	land/ person ha	fertilizer kg ha^{-1}	pesticides kg ha^{-1}	irrigated land %
Africa	181	0.27	20	?	6
Cameroon	7	0.59	3	0.4	0
Egypt	2.6	0.05	361	6.6	100
India	170	0.20	73	?	27
China	96	0.08	284	?	49
Costa Rica	0.5	0.17	212	11.8	22
Thailand	23	0.42	39	1.6	19
Germany	12	0.15	520	3	4
Belgium	0.8	0.08	470	11.8	0

(*b*) *Soil degradation*

The most obvious on-site damage arises from forms of soil degradation (Lal 1997). There are some encouraging signs that these problems can be overcome. A wide range of proven techniques are available to prevent erosion and maintain water quality, and many of these are relatively simple and inexpensive (Food and Agriculture Organization 1996). In a number of sites in Africa, Asia and the Caribbean, local farmers have banded together to develop soil conservation on a catchment basis (Pretty *et al*. 1995; Tinker & Anderson 1996) and have achieved significant successes. Where the farmers are truly convinced of the benefit of the work to themselves, and where they have the opportunity of participatory management, conservation works have often been successful (Pretty 1996). Despite earlier problems, agroforestry is now being used to control erosion, as well as providing other benefits (Ong & Huxley 1996; Sanchez 1997).

(*c*) *Local pollution of soil and water*

There will certainly be pollution from excessive or incorrect use of fertilizers and pesticides. Some of the developing countries now use rates for specific crops, such as cotton (tables 2 and 3), at least as high as those used in the developed countries (Prasad & Goswami 1992), and this must cause both accidents and pollution, though these are poorly monitored or documented as yet.

(*d*) *Local biodiversity effects*

Larger fields, fewer weeds, less plant diversity, fewer trees and hedges, and more removal of plant residues all damage local wildlife, though the impacts can be lessened (Orians & Lack 1992). The biodiversity in

Table 3. *Percentage of pesticide and land area used for different crops in India (after Jayaraj & Rabindra 1993)*

crop	pesticide share %	cropped area %
cotton	52–55	5
rice	17–18	24
vegetables etc.	13–14	3
plantation crops	7–8	2
cereals/oil seeds	6–7	58
sugar cane	2–3	2
others	1–2	6

the soil is likely to decline with both intensification and degradation (Greenland & Szabolcs 1994; Woomer & Swift 1994) with effects on the soil properties and the economic productivity which are still not fully known (Lavelle *et al.* 1994).

(*e*) *Local landscape value*

The landscape value of agricultural land is esteemed very highly in Western Europe, but in many developing countries it may rank rather lower. However, it can be very important for tourism, and there are many tropical agricultural landscapes that are both unique and attractive. It should not be neglected in a race for productivity.

7. DIRECT OFF-SITE ENVIRONMENTAL DAMAGE FROM AGRICULTURE

(*a*) *The catchment approach*

It is almost mandatory to use a landscape approach if both on-site and off-site environmental damage is to be assessed and corrected, and the most logical unit for this is the catchment. If properly chosen, this is a good sample of the soils, waters and topography, and in particular it allows the consequences of farmers actions to be traced down through a river system (Greenland *et al.* 1994; Tinker & Anderson 1996). Local/regional environmental effects are therefore best studied in the catchment context.

(*b*) *Nutrient pollution*

Increased use of fertilizers and organic manures can increase nutrient contents in surface and ground water; in surface water this can lead to eutrophication from algal growth. The increased amounts of organic materials cause increased biological oxygen demand, water bodies may became anaerobic, and eventually all biota may be killed (Ryding & Rast 1989).

Anaerobic conditions can also be caused by direct pollution with liquid organic wastes, such as from intensive cattle raising. They can also be generated by agro-industrial operations, such as sugar factories. In Malaysia there has been serious river pollution by the effluent from oil palm mills, but Government regulation has now reduced the problem to occasional accidents (Mohammed *et al.* 1987), and the effluent is normally recycled to the plantations as a useful nutrient source.

A more specific problem is that high concentrations of nitrate in drinking water can cause methaemoglobinaemia, or blue baby disease, but this is actually rather rare (Addiscott *et al.* 1991; Tinker 1991). The nitrate limit in drinking water has been set by the World Health Organization at 11.3 mg nitrate (N) l^{-1}.

To avoid nutrient pollution of ground or surface waters the nutrient cycle in arable farming must be kept under tight control (Greenland *et al.* 1994; Tinker & Anderson 1996); this is an essential part of what are now called integrated plant nutrition systems (IPNS) (Food and Agriculture Organization 1996). This requires exceptionally good management if large yields are aimed for, because the size of a crop is not known early in its growth when fertilizers are usually given. If farmers fertilize for maximum potential yield, but in fact only attain a fraction of this level, there must be a surplus of nitrogen left in the soil (Tinker 1991). Organic sources of nutrients may be even more difficult to control. Thus the average recovery of nitrogen in good intensive agriculture is around 50% or less (Crasswell & Godwin 1984; Tinker 1985). High yields and accurate nutrient control are difficult to achieve simultaneously, even in developed intensive agriculture.

In developing agriculture the same general principles operate. If fertilizer rates used are well below the optimum these problems do not occur (Reardon 1995), but the rates of fertilizer used in developing countries are now quite high where the Green Revolution has taken off (table 2) (World Resources Institute 1994). In India some 10 million ha are now under a two-crops-per-year rice–wheat system, that removes a total of 600–700 kg ha^{-1} of N + P_2O_5 + K_2O (Narang *et al.* 1994). Maximum yields were obtained with 180 kg N + 60 kg P_2O_5 + 30 kg K_2O, plus green manure for each crop. These rates are comparable with those used in intensive European agriculture.

There are many reports of high nitrate levels in water in developing countries following heavy use of fertilizer, but very little substantial and dependable data (e.g. Biswas 1995). In Sri Lanka high rates of fertilizer caused large seasonal changes in a shallow underlying aquifer, with maxima around 45 mg NO_3 (N) l^{-1} (Meybeck *et al.* 1989). However, up to the present the nitrate problem in drinking water is probably caused more by the close location of waste drainage tanks and wells than by fertilizer use.

(*c*) *Pesticide pollution*

Problems with pesticides cause more concern, because so many of them are toxins. Pimentel *et al.* (1991) estimated that the total environmental and social costs of pesticide use in the USA are $955 million per year. Worldwide there are over three million incidents of acute pesticide poisoning annually (Jeyaratnam 1990). Insecticides are used more in the tropics against insect disease vectors, i.e. to protect health, than against agricultural pests and diseases. However, about 50%

of rice farmers in the Philippines reported sickness after pesticide use (Tribe 1995). Organochlorine insecticides banned in the developed world continue to be used in some tropical countries, and statistics on the escape of pesticides to the environment are usually very poor. The human health issue is obviously dominant in the developing world, where other environmental problems connected with pesticides are rarely mentioned.

Figures for total pesticide use in different countries are not easy to get, but some developing world countries are using amounts per ha as large as those in West Europe (World Resources Institute 1994) (table 2). In India there is a significant local industrial production of some 100 000 t yr^{-1} (Jayaraj & Rabindra 1993). Certain crops such as cotton receive particularly heavy applications (table 3), so application is very non-uniform, and average rates may convey little information on local dangers.

Probably the best documented effect on wildlife is that of the organochlorine insecticides on the thickness of eggshells, and thereby on bird populations. Bird populations were badly affected by organochlorines in most developed countries (Sheail 1985), with raptors, at the top of the food chain, most at risk. The recovery of these bird populations after the banning of the chemicals is a very encouraging story, but the favourable outcome depended upon the vigilance of ecologists, and finally on Government regulation. An interesting account of the administrative and political manoeuvring in the UK during this process is in Sheail (1985). In this case the impact of the pesticides was therefore reversible, because it was detected and controlled in time.

In Zimbabwe DDT has been used extensively since 1946, and experience has paralleled that in the UK. Though it has been withdrawn from agricultural use since 1985, some 300 t yr^{-1} were still applied in insect vector control (Douthwaite *et al.* 1992). Metabolites of DDT have been found in a number of species, and the level of this in eggs was correlated with eggshell thinning for the fish eagle on Lake Kariba (Douthwaite 1992). It seems likely that there are many more such cases, but they have not been investigated or documented. It is difficult to know whether permanent damage is being done or not.

When agricultural pesticides are introduced, they may go through an initial phase of excessive use. The natural variability of pests and weeds means that most pesticide applied is not effective, with estimated average values for pesticide reaching the target organism being 1% (Tribe 1995) or 0.1% (World Resources Institute 1994, p. 114). This has contributed to the concept of integrated pest management (IPM), which is the use of biological or agronomic methods of control as far as possible, supported by the minimum use of pesticides (Teng *et al.* 1993). IPM programmes often aim to reduce total pesticide use by 50%, based on data showing that increased pesticide use has not decreased crop losses (Pimentel *et al.* 1991).

However, IPM (like IPNS) is more complicated to use than intensive agricultural methods, though the consequences are more acceptable. In India pesticide tolerance is becoming common, so IPM methods have been tested with some success, but are not always a complete answer (Jayaraj & Rabindra 1993). Release of biological enemies or introduction of resistant plant material can be very successful, as shown by the introduction of a parasitoid to control the cassava mealybug in West Africa (Herren 1989). The application of IPM on a large scale to control rice pests in Indonesia (World Resources Institute 1994, p. 116) has also been very successful, but Rogers *et al.* (1991) note that high biodiversity alone is no guarantee of low pest and disease levels, and that much better understanding of the ecology of the rice field is needed to use these methods reliably.

(*d*) *Water quality*

There are few data for general water quality in developing countries. There are undoubtedly local instances of severe pollution, but the average level of agrochemical pollutants in major rivers in developing countries is still well below that in Europe (Meybeck *et al.* 1989; Falkenmark 1997).

(*e*) *Siltation*

The amount of soil eroded in India each year is 5334 million tonnes, of which 2052 million tonnes is washed out to sea by rivers, and 480 million tonnes was deposited in reservoirs (Abrol & Sehgal 1994). The remainder is redeposited lower down the river courses, where it causes problems of siltation. The loss of the reservoir capacity of expensive dams within a few years of their completion is a huge waste of capital.

8. GREENHOUSE GASES AND GLOBAL CHANGE

The main outlines of the processes of global change leading to climate change are well known (Intergovernmental Panel on Climatic Change 1995*a*, *b*). Global change as a whole is caused by atmospheric composition change, climate change and land use change. Of these three, the last is already well underway, and is largely the subject of this discussion meeting.

Agriculture may normally generate greenhouse gases. A stable agricultural system will probably be at or near carbon balance, and so will not affect carbon dioxide levels. There will be a loss of carbon to the atmosphere on removing forest permanently. Of this, on average 30% comes from changes in soil and forest floor carbon and 70% from the forest itself (Houghton 1996). The soil carbon loss following deforestation may be gradually regained, depending entirely upon the use to which the land is put (Houghton 1996; Tinker *et al.* 1996). Both plantation or pasture establishment may allow some regain of carbon, and old pasture soils may contain as much carbon as that of high forest (Lugo *et al.* 1986). Deep-rooted perennial grassland may sequester significant amounts in the soil quite rapidly (Fisher *et al.* 1994).

The currently accepted carbon balance for the earth includes a loss of 2 Gt (Gigatons) C per annum from forest removal, and usually has a balancing term called the 'missing sink' (Intergovernmental Panel on Climatic Change 1995*a*). Recent results (Grace *et al.* 1995) have suggested that apparently mature forests, both tropical and temperate, are actually sequestering carbon at present, and that this could account for the 'missing sink'. If so, the total world forests in the present state of land use may be close to carbon balance.

The production of methane and nitrous oxide by agriculture is significant (Duxbury 1995; Intergovernmental Panel on Climatic Change 1995*a*). Wetland rice produces roughly 12% of the global methane, but the production of nitrous oxide by different sources is very uncertain. The relationship between nitrogen fertilizer rate and nitrous oxide production rate is important if nitrogen fertilizer use is to be increased, and the factor used by the Intergovernmental Panel on Climatic Change may underestimate the nitrous oxide production (Fowler, personal communication). Larger numbers of cattle, greater areas of rice and larger rates of nitrogen fertilizer will all increase the production of these gases. The net contribution of agriculture to the greenhouse gas budgets will be watched carefully.

The increasing carbon dioxide concentration in the atmosphere is likely to increase crop yields, and to reduce the transpiration rate of crops per unit of carbon fixed (Rogers and Dahlmann 1993; Rogers *et al.* 1997) but there are several complex interactions with other variables (Gregory 1997). At the carbon dioxide levels expected in 2020–2030, crop yield increases may be 5–10% (Goudriaan, personal communication).

The quantitative prediction of climate changes is still very uncertain, particularly for rainfall, which may well be the most important factor for crop yields (Intergovernmental Panel on Climatic Change 1995*b*). Significant climatic impacts on agriculture could occur before 2030 if rainfall or extreme events were affected, though the global mean temperature increase by then, from 1990, would only be around 0.5 °C. The developing states are expected to be most susceptible to damage by climate change (Tinker & Ingram 1996), and any impact would be more serious in sub-Saharan Africa than any other region (Schimmelpfennig *et al.* 1996). The potential interaction between climate change and agriculture may be important and complicated, and the 'global change' and the 'food security' scientific communities need to become even better integrated than now. It is to be hoped that any food crisis has been overcome before any climate change crisis develops.

9. BIOTECHNOLOGY AND THE TECHNICAL FUTURE

The limits and problems of the present main intensification technologies are well known. The two great advances in the 20th century that are relevant to agriculture are computers and biotechnology. Computers will allow more accurate control of farming operations and inputs in a variable environment, and hence reduce pollution, but this is still mostly at the research stage even in developed agriculture.

Biotechnology has more immediate promise and dangers, because genetically engineered cultivars of many cultivated species are now appearing (World Resources Institute 1994). Pest, disease and herbicide resistance are the most likely qualities to be provided in the near future (Persley 1994), but salinity, drought and acidity tolerance may become available later. The main environmental concern is about release of genetically modified organisms–including microbes–and the possibility of unexpected effects (Raybould & Gray 1996). Regulation of release of genetically modified organisms is essential, but it is unlikely that regulatory control will be adequate in all parts of the world. This will be a very serious issue in the future.

10. THE ENVIRONMENTAL FUTURE

Environmental concern may be proportional to affluence (but see Antle 1994), and it may therefore be considered of trivial importance for developing countries. This is however too simple. First, some issues impact directly on both food production and the environment. Second, much of the action to prevent food shortages is influenced by organizations that have strong environmental principles. Third, some tropical countries are already reacting against environmental damage, and see that prevention of such damage is in their own interests. At a practical level, if the poorest countries receive support from the developed world (both temperate and tropical), aid budgets could be used to help them in this regard. The environment cannot be ignored.

The contention of this paper is that there is a high probability of serious environmental damage in the developing countries over the next 30 years, due to environmental problems becoming marginalized by the need to produce more food. What can be done to minimize this, especially the irreversible or very slowly reversible changes?

The first need is for better and more up-to-date environmental data to determine the critical issues and trends. Such data are at present difficult to find, or not dependable. Some environmental writers have damaged credibility by excessive claims based on poor evidence. These data are also needed for environmental models of various types (Alcomo 1994). All observations need to be regular, on carefully selected and representative sites, and made by uniform and properly validated methods. The total task is enormous, and will need all the encouragement that the developed world can give.

The sources of such an improved information flow are not yet clear. National sources will improve, but will remain very variable. Aid budgets could be directed towards improving environmental data, and it is important that the recipients should come to see that this is in their own long-term interests. McNeely & Norgaard (1992) have discussed various political factors in this. International agencies are involved, for example the United Nations Environment Programme and the Food and Agriculture Organization. The Global Terrestrial Observing System (GTOS), now managed by Food and Agriculture Organization, is developing, and should eventually have a major role in this area. The need for such an organization is becoming more urgent.

Second, the selection of indicators of environmental quality is important, to give the earliest possible warning of environmental problems. Land quality indicators are particularly difficult because of the complexity of the concept of land quality, and much progress is still needed (Pieri *et al*. 1995). Evironmental indicator values for a whole range of different variables are being assembled in the industrialized states (Department of Environment 1996), and this should be done elsewhere. However, environmental effects can occur unpredictably (World Bank 1995), and one should not be tied to a rigid set of indicators; constant vigilance is necessary.

Third, it is essential to get support from local people so that environmental damage due to agricultural change and intensification can be prevented or reversed. The direct on-site problems that reduce production are likely to get strong attention (Food and Agriculture Organization 1996). The imperative need is to get a positive response from farmers to environmental programmes, by a judicious mixture of encouragement, subsidies and regulation. Some of the possible ways have been outlined by Pretty (1995). The need to maintain efficient farming needs to be stressed, and it is vital that advice to farmers must be correct, as poor advice based on inadequate research loses the farmers' trust. The output of general statements is enormous, but the actual procedures are less often defined. These procedures are often fairly simple, but site specific, so that the farmers skill and the provision of good advice are the key ingredients.

However, a range of off-site problems has been discussed in this paper, which are less easily costed in economic terms, and of progressively less obvious interest to local farmers. The danger is that these will be ignored, and especially those for which cost–benefit calculations are most difficult, because the damage cannot be quantified in monetary terms. If the race between food and population over the next three decades is close, these environmental goods may be ignored. This would be a tragedy, because the environmental problems of intensified land use can be controlled, given the will. The real problems arise where control appears to be of little direct advantage to the farmers, and where they are being asked to carry responsibilities or costs for reasons that are mainly of interest to the developed world. We must consider words attributed to Ross Perot, the American presidential candidate, about the logging of forest containing the northern spotted owl in the United States (Ward Thomas 1996): 'If our children are hungry, we will cut every last tree. And we will not worry about the spotted owls, except maybe to eat them'.

The developing world has the opportunity to intensify its agriculture and safeguard its food supply with less damage to the environment than that originally caused by intensification in developed countries. However, the opposite can easily happen.

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Discussion

R. Lal (*Ohio State University, USA*). It is the extensive agriculture in Africa south of the Sahara which is the cause of widespread degradation, and science-based intensification is the solution to the problem. I also believe it is important to educate the people about uses and abuses of pesticides.

P. B. Tinker. I am sure we agree that if intensification is done properly, with site-specific knowledge, then it should cure the problem, though there will be many areas that will not be suitable for intensification. As I said earlier, the important issue is whether that knowledge, and the ability and resources to apply it properly, is available. Badly done intensification will not solve present problems, and it may add new ones. I agree very strongly with you about the pesticides problem.

P. Bullock (*SSLURC*, *Cranfield University*, *Silsoe*, *UK*). One impact of soil erosion due to intensification is heavy sediment loads in rivers leading to death of fish. This may necessitate changes in land use.

P. B. Tinker. Yes, there is certainly a problem here, especially if the eroded topsoil contains nutrients and agrochemicals. The whole ecology of a river could be changed by a situation like this. The written paper contains a comment about this problem.

C. Valentin (*ORSTOM*, *Niger*). Your paper stressed the detrimental off-site effects of water erosion. I would like to point out that much of the fine material in West African soils is deposited by wind, from dry lake bottoms in the Sahara.

P. B. Tinker. This is of course right, but I think it is a matter of degree and time. Slow deposition of fine material can be valuable, as you say, but heavy deposits laid down over a short time, as in the US Midwest in the 1930s, must cause damage.

J. Kijne (*International Irrigation Management Institute*, *P.O. Box* 2075, *Colombo*). I strongly agree with the need for soil and water conservation on a catchment basis. At present we do not know what effect extensive soil conservation has on river flows, and hence on availability of water for irrigation.

I want to support the point about 'people's management' in relation to management of natural resources. This is still not sufficiently supported at official level.

P. B. Tinker. I think both points are in agreement with the paper, and I am glad to have your support.

H. Fell (*ABAS*, *Barton on Humber*, *UK*). Intensification does not necessarily lead to degradation of soil.

P. B. Tinker. Of course that is correct, and the whole tenor of my paper is to stress that we must have intensification, but without the degradation of soil or other environmental impacts that have often happened in all parts of the world. The point is that this needs scientific and technical knowledge, and the managerial abilities to apply this.