

Review

Sustainable practices to limit soil erosion: a review and discussion

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Received: 23 June 2006

Accepted: 25 July 2006

doi: 10.1079/PAVSNNR20061030

The electronic version of this article is the definitive one. It is located here: <http://www.cababstractsplus.org/cabreviews>

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Abstract

How the review was carried out is briefly described. The review looks mainly at the literature published since year 2000, but does not exclude earlier publications. The sustainability of practices to limit erosion must be assessed not only in terms of the soil resource and the wider environment but must also take into account economical and socio-political factors. Soil degradation may be due to a number of causes and it may be that in places erosion is not the main factor. So how erosion is assessed and perceived may be an important factor if degradation is to be successfully tackled. Certainly, in many parts of the world farmers do not, or cannot, combat erosion. A brief history of soil conservation practices is given and then these techniques are examined in more detail in terms of their environmental, economical and socio-political sustainability. Many practices are environmentally sustainable, especially those used by small indigenous farmers, but few are sustainable in financial and socio-political terms. Although conservation tillage techniques are being vigorously promoted they may be more sustainable when carried out on small farms where no herbicide inputs are needed. It is the economical and socio-political factors that lead to erosion which need to be tackled if sustainable practices to limit soil erosion are to be successful.

Keywords: Erosion, Conservation, Sustainability, Economical and socio-political factors

Review Methodology: The abstracting service CAB DIRECT was interrogated and abstracts from those papers with titles indicating their relevance to the review were downloaded. I concentrated on land that grows crops and supports animals and I searched the database back to the beginning of year 2000 for titles or abstracts containing the words 'soil erosion'. I used a broad 'trawl' approach as a preliminary trial using other key words had identified very few relevant articles. The search produced over 1400 articles of which the first 1000 were scanned. I then interrogated the Agricultural Economics and Rural Studies database, again back to 1, January 2000, and again using the words 'soil erosion'. Over 400 articles were identified, a few duplicating the first search.

All together 153 abstracts of what appeared to be relevant articles were downloaded. Of these 85 were from journals, 15 were chapters from books, nine were from Bulletins, five were PhD theses and three were other papers and proceedings. The articles described relevant work on practices for limiting soil erosion from 47 countries, of which 18 articles described work in the USA, 17 referred to China, 11 to India, nine to Ethiopia, six to Kenya, and four each to Honduras, Nepal, Peru and Tanzania.

To write this review, I refer to the relevant articles and also to those I already knew about. I have not read all the articles, for not all are easily available from local sources, even though I have access to good libraries. For example, only 38 of the 85 journals in which the abstracted articles appear are easily accessible in the libraries of Cambridge and Anglia Ruskin Universities. Interlibrary loans and access to articles over the internet are not free and it would have been costly to obtain all those articles that looked of interest. However, it seems likely that the abstracts and articles perused give such a widespread coverage of soil conservation practices in so many countries that they give an adequate sample to examine whether practices to conserve or limit soil erosion are sustainable.

Introduction

The title of this review is carefully chosen. It accepts that erosion can only be limited, or curtailed, not stopped. It also accepts there is a tolerable level of erosion, this is arguable, especially if the view is taken, in my view rightly,

that soil is a finite resource [1]. 'Sustainable' implies that the needs of the present are met without compromising the ability of future generations to meet their own needs [2]. However, the goals of economic and social development must be defined also in terms of sustainability [3]. Agriculture has an important role to play in encouraging

economic growth and poverty reduction in developing countries, but '*Sustainability is not an optional issue, it is fundamental to achieving future growth in agriculture. Agriculture is sustainable when it balances ecological, economic and socio-political trade-offs*' (para 84, page 23; [4]). This 'balance' is difficult to achieve.

This review is written from the perspective of a researcher who assesses erosion of agricultural land in the field, and those fields are in a country where climate and topography are not extreme, and where erosion extent and rates [5, 6] and sediment delivery to streams [7] are low. Nevertheless, such field assessment of erosion and its impacts have shown that even low levels of erosion, far lower than the generally accepted tolerable level of about 11 tons ha⁻¹ yr⁻¹ [8], equivalent to a surface lowering of about 1 mm yr⁻¹, can have serious impacts on water quality because of the pollutants (sediment, nutrients, pesticides) carried in runoff from the fields into water courses. Such pollutants have to be removed from the water before it can be drunk, a costly procedure [9–11] and the impacts of 'muddy floods' can be severe [12, 13]. Regulations in developed countries such as the USA and those in the European Union are bringing protection of soil and water quality to the fore, with important implications for agriculture.

Another way of defining what is a 'tolerable' level of erosion is that level which pertains prior to land being used for agriculture in an intensive manner. What may be called the 'background' level before intensification took place, in England and Wales this resulted in sediment yields in rivers of about 0.2 tons ha⁻¹ yr⁻¹ [7], although this varied somewhat according to land use, rainfall and topography. Evidence suggests that over the last 50 years, as agriculture intensified – greater use of artificial fertilizers, larger fields, bigger machines, fewer people working the land, less grass in the crop rotation, growing of crops more vulnerable to erosion, continuous arable or more intensive stocking rates, decline in organic matter – soils have become more at risk of erosion. And sediment yields have probably doubled, or more (>0.4 tons ha⁻¹ yr⁻¹). It is likely that in many parts of the world, where rainfall is more intense and slopes steeper it may be difficult to attain 'background' sediment yields once much land is converted from forest or grassland to agriculture.

The lack of uptake by farmers of methods to limit erosion has resulted in many assessments as to why this has happened [14–26]. The poor uptake of schemes has many causes: schemes have often been 'top-down', erosion has not been perceived as a problem, co-operation between institutions has been poor, the schemes were not economic unless subsidised in some way, and socially and politically unpopular, especially in some African countries where such schemes were forced on indigenous populations by the then colonial power [27].

Other assessments, often involving many participating individuals and organizations, have been made to work out how to encourage farmers to manage their land in

a more sustainable way and to participate in schemes devised to curtail erosion [24, 28–33] but so far with few positive results unless projects addressed multiple goals, such as reducing soil loss and flooding, increasing dry season flows and improving the economic value of land and the livelihood of people [34–36]. Both the World Overview of Conservation Approaches and Technology (WOCAT) [37] and the World Association of Soil and Water Conservation (WASWC) [38] play important roles in trying to persuade farmers to use their land in a more sustainable way.

It is because the economic and socio-political factors have to take precedence over environmental ones – people have to eat if they are practising subsistence agriculture, as in many developing countries, or have to make a profit where farming is run as a business, as in the developed world – that practices to curtail erosion are not often taken up, for such practices are generally not economic.

Furthermore, many farmers are not aware that their actions in growing crops or grazing their animals have deleterious effects on the productivity of their land or have serious impacts on their downstream neighbours. Indeed, in developed countries it is likely the off-farm impacts are far greater than they are on-farm [9, 13]. It is important here to recognize therefore that what may not be financially viable for a farmer could well be economically viable for the community as a whole, or the nation, because of the off-site impacts and costs of erosion.

It is likely that in many parts of the world, it is loss of soil fertility, because nutrients taken up by the crop are not replaced by fertilisers, rather than erosion [39], that is the biggest problem for farmers. Compacted soils may also severely inhibit crop growth [40]. In other words, is erosion the problem or just a perception? It is becoming widely acknowledged that our knowledge of the extent and severity of erosion is poor [5, 41, 42] and, although there is better information than there used to be [43] and efforts are being made to improve the quality of information [1], we need better ways of assessing erosion [13, 44–47].

Also, if erosion is mainly by sheet wash rather than by rills and gullies, it is more difficult to discern, and often in such circumstances, the rates of erosion will be low and hence will be ignored. This observation leads to a fundamental point, how erosion is assessed is critical, thus the problem of erosion, as far as the 'expert' is concerned may appear severe, whereas it is not in the eyes of the farmer. Most ways of assessing erosion are done by using formulae based on plot experiments, and often overstate [48, 49] or mis-state [50] the problem of erosion. These differences in perception of erosion, between farmers and 'experts' may well explain why many soil conservation programmes have failed, especially in developing countries [51, 52].

When economical and socio-political factors control the decisions taken by farmers, the approach is almost of

necessity a short-term one, unless food or money surpluses are being generated rapidly to allow investment for the future. Long-term impacts such as the decline in soil depth and hence on the water holding capacity of the soil which controls crop yield, providing nutrient levels are satisfactory, are difficult to envisage. However, even in England and Wales, since the land has been settled and used for agriculture over a period of about 4000 years, soil thinning has resulted in yield reductions of at least 10% [13]. In countries where climate and topography are more severe, such impacts will occur far more quickly.

Hudson (page 16, [52]) has suggested that 'loss of productivity is a better measure of degradation than soil lost' but loss of productivity can be due to a number of factors – decline of soil fertility [39], soil erosion, soil compaction [40] – and unless the main contributing factor is known the problem of lost productivity cannot be remedied effectively.

There is a pressing need therefore to employ practices to limit soil erosion. I will describe briefly how conservation practices have developed, and then discuss in more detail some presently used practices and some of the problems associated with them which may explain their general lack of uptake, and then draw some conclusions about how a better uptake may be brought about.

Practices to Limit Soil Erosion

It is appropriate to briefly describe the evolution of soil conservation techniques. Since the early 1900s when soil erosion came to be accepted as a problem [53, 54], especially of cultivated land, many practices have been designed to curtail erosion. Originally, many of these practices to combat water erosion were based on earth moving and the construction of terraces of various types, especially in the USA and Australia and former British colonies in Africa and the West Indies. Planting along the contour and strip cropping were also promulgated, as well as grassed waterways. Strip cropping and shelter belts of various kinds were also encouraged to stop wind erosion. These practices are dealt with in many text books [55–58].

As it was realized that a certain amount of crop or stubble cover (25–30%; [59]) was sufficient to disperse raindrop energy and greatly inhibit runoff and erosion, minimal or no tillage was encouraged so that seeds were drilled into a protective live or dead ground cover. In intensive agriculture, this relied on a herbicide to kill off the weeds which were likely to compete with the growing crop. Effective herbicides, used to defoliate the jungle in the USA/Vietnam war of the late 1960s/early 1970s, became widely available after the war ended. Minimal or no-till techniques allow large areas of land to be worked quickly using large machinery and with few workers and allows crops to be grown more cheaply [60]. It was for

those reasons that the practice became widely favoured and was later promoted as conservation tillage. Conservation tillage is now widely used in USA, Argentina, Brazil, Australia, Canada and China and is being widely promoted throughout the world by both commercial organisations and the United Nation's Food and Agriculture Organisation [61–63].

With further technological advances other practices based on stabilizing the soil surface and soil aggregates have come to the fore, particularly in the 1990s, and are now being vigorously promoted [64–68].

The above comments relate to agriculture in those parts of the world where crops are grown as part of a business venture, often for export. Where crops are grown as part of a subsistence economy, it is often on a very small scale, and many different crops, shrubs and trees may be grown in close juxtaposition to each other on small plots. Such small-scale indigenous farming is considered sustainable [69, 70]. Erosion on small plots is often low or negligible compared to more intensively cultivated land [71–74]. In tropical forests, until population pressure becomes severe 'slash and burn' agriculture (=shifting cultivation (Jhum)) on a long cycle, say 10–12 years is the lowest cost source of growth [75], and does not lead to much erosion by water [76] or by mass movements. The system is resilient and once reforestation starts taking place, runoff and erosion levels soon revert to their previous low levels [77]. Poverty does not necessarily lead to degradation of the land [78].

Terrace agriculture is presently practised in many parts of the world, especially South East Asia, as it was in many parts of the Mediterranean basin [79], and parts of England, for example, in Medieval times. In many places the construction of terraces was, or is, more likely a response to the need for land which is level for cultivation and irrigation rather than to minimise erosion, although it does that too.

There is considerable evidence therefore that suggests that often, until population pressure becomes too severe, indigenous types of arable agriculture have negligible or low erosion rates. But even so, as shown above in England, the impacts on soil productivity can be large over the long term.

In many parts of the world too dry for growing crops without irrigation or too cold for cultivating crops animals are grazed. Often, before the boundaries of countries became fixed, the animals roamed unimpeded over vast areas and it seems likely erosion was not widespread, except perhaps around the Mediterranean Sea and parts of China [80], or at particular 'hotspots', at river crossings for example. Once the extent of grazings becomes limited or animal numbers are greatly increased, the chance of bare soil being exposed and eroded by water and wind is greatly increased [15, 46, 81]. Again, as for cultivated land, what evidence there is suggests that in many parts of the world indigenous grazing practices did not lead

to high erosion rates. In other words, such land uses were as near as possible sustainable.

Sustainability of Practices to Limit Erosion

As noted above, except for conservation tillage in some form or other, and terracing in South East Asia (and the Mediterranean basin in the past), practises to limit erosion have not been widely taken up. In the following sections, I discuss the evidence for the sustainability of practices to limit erosion not only with regard to the conservation of the soil and its environment but also with regard to the economical and socio-political sustainability of agricultural communities.

Grazing Land

The most sustainable practice to limit erosion is to leave the land as forest or grassland with a low grazing intensity. Where erosion of grazed land is occurring in a developed country often, as I saw in New South Wales, Australia, in 1992, concrete spillways and pools had been constructed to prevent further gullying, but no effort was then being made to tackle the actual cause of the problem – too many animals grazing the land. Animals, mainly sheep, had not only created bare soil but had so tightly grazed the sward that runoff was almost instantaneous in winter when soils were saturated [82]. Much of the sediment transported down the gullies originated from the gullies themselves, due to headward retreat and widening, not from the heavily grazed paddocks. In many parts of the world, gullies created by runoff from overgrazed land have stabilizing structures or vegetation inserted within them [57], but little attempt seems to be made to address the underlying cause that too many animals are grazing the land. Unless the socio-political and economical factors leading to overgrazing are tackled erosion will continue. These factors need to be addressed not just in developing countries, such as Mongolia (R. Evans and K. Stafford, personal communication) but also in highly developed countries, such as Norway [83].

Overgrazed land may recover, at least it will often regain a permanent vegetation cover which inhibits erosion, if livestock are kept from the land [84, 85]. However, this is often not a financial proposition for the farmer. In England it has been found in some soil/vegetation landscapes that reducing by about 30% the grazing pressure that leads to erosion has led to recolonization of the bare soil by vegetation [86]. Under appropriate land management agreements, in this case between tenant and land owner and taking account of Government subsidies, the farm appears still to be an economically viable unit.

Research needs to be carried out to ascertain what the grazing intensity thresholds are that lead to the

creation of bare soil. This can only be done by monitoring grazing and its impacts in the field. Then, rules and regulations need to be devised with the graziers to make those stocking levels viable economically. Such grazing regimes may have to be based on a rotational stocking system with care taken to ensure that trampling along fence lines does not lead to the formation of bare soil and gullies.

Cultivated Land

The practices briefly described above and analysed below are, for the sake of brevity, and based on their similarities, classified and described under five headings: earth-moving; barriers to water flow and wind blow; ground protection; better land management; and surface stabilisers. The practises will not be described in great detail, but in terms of their sustainability.

Earth-moving practices

Terraces of some form or other, there are many kinds [57, 79], require soil to be moved and the 'steps' between the terraces protected from erosion by water or mass movements by vegetation or stonework. In terms of time and effort, they are expensive to construct and maintain. However, in many parts of the world, it has been only by constructing terraces that enough land was made available for cultivation to feed growing populations. When first built therefore they were sustainable both to the farmer and to the community in the economical and socio-political senses as well as protecting the soil from erosion. Terraces limit erosion [87–89], and hence are more sustainable in resource terms, and become more economical as population densities increase [75]. Presently, however, unless economical and socio-political factors are tackled to encourage people to build, farm and maintain terraced slopes, and that a food or crop surplus is produced to enable a satisfactory standard of living to be maintained, they will not appear to the farmer a financially attractive practice for sustainably limiting soil erosion [22, 87, 90].

In localities where water is scarce, it may be terracing will only be successful if water supplies are also ensured to improve crop yields so that conventional agricultural plots from which there is runoff are combined with conservation bench terraces [91].

Terraces which are not maintained may themselves trigger further erosion as mass movements or animals destroy the 'steps', or gullies can form at the 'steps', and in parts of the Mediterranean basin such erosion is occurring [79].

Barriers to water flow and wind blow

In many less developed countries of the world ways have been devised of holding up water flowing across the land so that it infiltrates into the soil rather than runs

off. If the barriers are spaced closely enough the runoff will not gain sufficient velocity to incise into the land, though particles may be transported by wash. Low terraces [32, 57], stone rows [92], soil [32, 90] and stone bunds [93], pits [69, 94], trenches [94], ridges and furrows [95], and ditches [89] can all limit erosion, but often their greatest advantage is that such structures can also improve crop yields by trapping rainfall. The soil particles which are trapped behind the barriers increase soil depth, and 'steps' or terraces may form, and crop yields in the vicinity of the barriers increase.

Strips of grass [57, 96], or shrubs and trees [57], and hedgerow intercropping along the contour also act as barriers to flow and cut down erosion [37, 71, 74, 92, 97–100].

However, uptake of such techniques is often low because farmers see little benefit [19] or are constrained by lack of money [20, 71]. Vetiver grass [101] has been widely promoted as material to form barriers to water flow in the warmer parts of the world, it is intolerant of frosts, but its uptake does not appear to be widely reported. Again, this is more likely to be related to financial and socio-political factors than it is to any perceived failing as a soil conservation technique. It may also be that such an approach is seen to be largely a top down one pushed by aid agencies and the World Bank, and does not take sufficient account of local social and economical factors.

Barriers to inhibit wind erosion, lines of shrubs or trees or strips of grass or stubble, have been widely researched and promoted [57] but may not always be used where appropriate. Again, this is not because the techniques do not work, but because they are considered not financially viable by farmers in the light of the agricultural economy prevailing at the time. An example can be given from the peat fenland of Cambridge and Norfolk, England where shelter belts were investigated and promoted [102, 103] and occasionally planted to prevent wind erosion but by the latter decades of the twentieth century had often been removed and worse, drainage ditches had been infilled to form larger fields which were more economic (for the farmer) to work but more vulnerable to wind erosion.

Ground protection

If the ground is protected by a vegetation cover, or is left rough by cultivation, rainfall infiltrates faster and runoff is impeded. However, if rainfall is intense enough and in sufficient quantity erosion can take place even of bare cultivated surfaces, a phenomenon I have seen not only in large chisel-ploughed fields in Wyoming, but in ploughed fields in England. Boardman [104] has described such erosion on chalk downland in Sussex, England. A vegetation cover of 25–30% [59] appears sufficient to severely limit erosion. However, until practices were devised in the 1960s and 1970s which allowed seeds to be drilled into a stubble or mulch large scale intensive agriculture

could not derive such soil conservation benefits. What came to be called conservation tillage sprang from a desire to reduce fuel costs by cutting out ploughing, harrowing and seed bed preparations and also to combat erosion in the mid-western states of the USA. Direct drilling was the ultimate aim, but often a cultivation to encourage weeds which could be sprayed off and then drilled was acceptable.

Conservation agriculture '*implies conformity with all three of the following general principles: no mechanical soil disturbance, direct seeding or planting; and permanent soil cover, making particular use of crop residues and cover crops; judicious choice of crop rotations*' (page v, [61]), but elsewhere in [61] it makes clear that herbicides are essential for successful conservation agriculture. The main aim of conservation tillage and of no-tillage seeding [105] is to disturb the soil as little as possible and to maintain protective vegetation, and to maintain (or increase) soil organic matter levels. Conservation agriculture and minimum tillage can be carried out on smallholder farms and without using herbicides [106, 107] and is probably the most sustainable practice known to limit erosion and also keeps people on the land rather than fleeing to cities [108]. However, a distinction needs to be made between the small scale conservation agriculture not using herbicides, which keeps people on the land, and the larger scale conservation agriculture dependant upon herbicides, which generally reduces the number of people working the land. The former is more sustainable than the latter both environmentally and socially.

In England, and in other countries too, it was the economic benefits of minimal tillage (later called conservation tillage) which were promoted rather than the protection of the soil. It is because conservation tillage appears to be of direct economic benefit to the farmer [60] that it has been taken up so widely, especially in those countries where agriculture is highly mechanised. In England, however, when such practices were first promoted in the 1970s although at first they were taken up widely, reduced yields and problems with pests led to a decline in the application of the techniques. The technique worked well on some soils, but not others, and in many rotations which included sugar beet or potatoes, for example, the plough was still needed, so needing two sets of machinery. As drills have improved, allowing a wider range of crops to be drilled followed by good germination rates, and farming has got less profitable in England so there has been wider promotion of conservation tillage. Going down this route can allow farm workers to be shed.

Conservation tillage is seen as a way to limit runoff and erosion that will enable farmers to comply with European Union and English regulations to keep their land in 'good agricultural and environmental condition'. Limiting runoff and erosion will also improve water quality. By 2015 river water quality in European nations has to be of 'good' quality, though 'good' is as yet undefined. The target year

is set by the European Union's Water Framework Directive. If farmers do not comply with keeping their land in good agricultural and environmental condition they will not get (all) their subsidies. It appears therefore that conservation tillage may be the major way forward to protect soils where the land is being used for large scale agriculture. It is being promoted widely (see above).

Erosion can be greatly reduced by conservation tillage [109–113], though runoff may not be reduced by the same proportion [112]. Research findings are not always clear however. At a site in England erosion from minimally tilled plots was about 60% that of the standard plots although there was no statistical difference between the results [114]. On the minimum tillage plots plant debris after harvest was incorporated into the top 10 cm of soil whereas on the standard plots plant remains were removed and the soil ploughed. However, another plot experiment at another site in England carried out to assess which tillage system cut down runoff and erosion most showed that ploughing in of straw was far superior to conservation tillage [115]. Conservation tillage will reduce pollution of water courses [116] but even small amounts of phosphate-enriched clay particles [117] may cause eutrophication of water bodies.

Poisonous pellets to control slugs which may damage crops, also kill other species and may impact on the biodiversity of the field and adjacent water courses. This may not matter in Chile (C. Crevetto, personal communication) but it does in the UK. Although conservation tillage is promoted as increasing the organic matter of the top few centimetres of soil and encouraging worms to inhabit that layer, a crop rotation which still necessitates the use of the plough mitigates those advantages. Fuglie [118] worries that the adoption of conservation tillage may lead to too great a reliance on agricultural chemicals. These and other problems that restrict the uptake of conservation tillage are outlined by Harrington [119] and Rockstrom *et al.* [120].

There are three major caveats with regard to conservation tillage. The first is that if herbicides are not applied under the right conditions they will be carried to water courses either in runoff or drain flow. This has serious implications for the water supply industries in developed countries such as the European Union and USA for they have to provide drinking water which by law must meet stringent requirements. It is costly to remove pesticides from water and the general public must bear that cost when it is passed on. Secondly, the production of pesticides relies on the continuing and economic supply of petroleum products. This may not be guaranteed far into the future [121]. The third caveat relates to weeds acquiring resistance to the herbicides used in conservation tillage, for example rye grass in Australia [122]. Alternative herbicides are probably less benign than those used now. If herbicides cannot be used is conservation tillage a viable agricultural practice on large farms? Only from a short-term financial viewpoint

therefore does conservation tillage appear to be a sustainable practice.

Organic and non-organic mulches, if available, cut down runoff and erosion world wide in cropped fields and plantations [123–128].

When arable land vulnerable to erosion is set-aside to grass the extent of erosion declines and the connectivity of flow down-valley is lessened, this change has been monitored in a catchment on the chalk Downlands of West Sussex, England [129]. In the USA government subsidies encouraged the take up of set-aside and will have had similar impacts. Off-farm impacts of flooding can be severe. In West Sussex, houses which had frequently been flooded prior to the land being set-aside were not flooded even in autumn 2000, when a sequence of storms happened estimated to be of a 1 in 350 year occurrence. Elsewhere on the Downs flooding of property was widespread [12]. The farmer could afford to set aside his land because he was paid an agricultural subsidy to do so [130]. However, the subsidy had not come about as a means to combat erosion, but as a means to stop overproduction of combinable crops, for the European Union had a surplus of cereals and it was expensive to store these or to subsidise their export.

Better land management

That set-aside reduced the extent of erosion and severity of flooding was not unexpected. When grass or legumes are included in the crop rotation soil erosion rates decline for the land is protected from erosion in those years. The soil's structure is also improved and when the land is ploughed up again, especially if the land has been under grass for 3 years or so, for a time the soil is more resistant to erosion. When there was an economic basis for a grass-based rotation, prior to the Second World War before cheap nitrogen fertilizers became widely available in the developed world, there was little evidence for runoff and erosion in England [13]. In the wetter west of the country the farm was dominantly under grass whereas in the drier east arable land was dominant. With the decline in area of short-term ley grassland and its replacement by continuous arable, as well as a change in cropping since the late 1960s, erosion has become much more evident [7]. In other countries too, rotations with more grass in them cut down erosion [131–134].

Growing trees or shrubs on vulnerable slopes or interspersing them between crops (agroforestry) will also cut down runoff and erosion [71, 135, 136] and connectivity [137]. Alternatively, grass cover crops [138, 139], or intercropped vegetables [110] or even weeds [140] can be grown between trees or shrubs, as on coffee or tea plantations. The incorporation of manure or compost into soils so improving soil structure also cuts down runoff and erosion [96, 141, 142] and phosphorus losses in water [116]. However, as Stocking (page 21, [33]) notes when discussing 'hillsides production systems', *"All projects, in varying ways, emphasize the factors*

that limit the adoption of available technologies” but “While financial, physical, and natural capital assets are extremely limited, social and human assets enable people to overcome the difficulties of their environment and secure their livelihoods.”

Surface stabilizers

Petroleum-based products can be used to stabilize the soil surface and to encourage soil particles and small aggregates to cohere to form larger aggregates [64–68] which are more resistant to transport by water and wind and can improve the infiltration capacity of the topsoil. Such products have been on the market for the last two decades and a particular product, PAM (polyacrylamide), has been vigorously promoted since the mid 1990s, especially for irrigated farmland [64, 143, 144]. As with other technologically driven techniques to alleviate erosion there are caveats. In this instance, the costs of the practice can only be covered by growing high value crops. To spray large areas of land to grow cereals, for example, is not a financial proposition. More importantly, petroleum products are themselves a finite resource and it is estimated that peak production has been, or shortly will be, attained [121]. Some doubts have been raised about the toxicity of the chemicals in the runoff which reaches water courses [145]. On resource, financial, economical and environmental grounds therefore such synthetic treatments of soils are probably not sustainable.

Conclusions

World wide, and in many agricultural systems, environmentally sustainable practices have been devised to limit erosion. But, world wide, except possibly where indigenous agriculture prevails and population pressure is low, these sustainable practices are not taken up because financial, social and political factors over-ride environmental needs.

Farmers need to be made (more) aware of (i) the long term impacts of erosion on crop yield, (ii) the impacts of runoff and erosion on their downstream neighbours and (iii) the impacts of runoff and erosion on the biodiversity of the rivers and oceans [41].

It is not difficult to devise strategies for protecting soil. What is difficult is persuading farmers to take actions to do that. Short-term actions must always over-ride actions that result in long-term benefits, for farmers have to eat and make enough money from selling their agricultural produce to buy food if they are not themselves self-sufficient and to buy other necessities, and to enable many people in developing countries to improve their standard of living. Hence, presently a practice that limits soil erosion and is sustainable in the resource sense, is rarely sustainable in the financial and socio-political contexts.

There are good economical and socio-political reasons for keeping people employed on the land, and stopping their flight to the cities [3]. But to retain those populations and to protect the soil all the three bases of sustainability – resource/ecological, financial (for the farmer)/economical (for society) and socio-political – need to be satisfied.

In my experience, if farmers accept there is a problem such as runoff and erosion, they are more than competent to solve it [130, 137], providing they will still be making a living. Very often farmers are not aware of the impacts on others of what they do. In some developed countries if farmers do not take heed of these warnings, litigation may ensue, to their disadvantage [146] but persuasion rather than coercion seems a better way. Indeed, co-operation and participation are essential if progress on limiting soil erosion is to be made.

The main difficulty therefore in devising sustainable practices to limit erosion is not the devising of the practices but is in designing the economical and socio-political schemes which will encourage farmers to take up the soil protecting practices, and which will overcome the financial, institutional and cultural barriers presently impeding uptake. Such schemes must produce a financial return to the farmer to not only make s/he want to protect the soil but to continue farming in such a way that they also improve their standard of living.

Prices of agricultural products must be such that they return a reasonable profit to the farmer, perhaps ‘fair trade’ shows the way here. Or, subsidies must be such that combined with prices they make it worthwhile for the farmer continuing to grow crops and animals. Hence it is likely a mix of market and government subsidy approaches is needed, tailored to the needs of individual countries and especially aimed to help the agricultural sector in the developing world. The World Trade Organisation must therefore look closely at how trade in agricultural products develops and is conducted in order to take into account not just the economical factors which largely seem to govern its attitudes to trade but, and more importantly, takes account of the resource and ecological aspects, as well as socio-political aspects, of sustainability. As noted elsewhere [147], taking such a path may have serious economical and socio-political impacts on urban dwellers.

In tackling these problems of resource sustainability, particularly as they affect soils, there is scope for using fertiliser, water and pesticides more efficiently, following an integrated or whole farm approach. Infrastructure off the farm – roads, improved communications – may also need to be greatly improved to allow agricultural produce to be moved easily and quickly to markets. Indeed, concentrating on improving the infrastructure and other socio-political factors, especially education, particularly for women, may greatly help in encouraging the uptake of sustainable practices to limit soil erosion.

Acknowledgment

An anonymous referee made very helpful suggestions to improve the manuscript.

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