ISSN 0966-8616

Agroforestry Forum

December 1997 Volume 8 Number 4

Special issue on the control of soil erosion and fertility on sloping land

Contents

Editorial

This issue focuses on contour hedgerows - an agroforestry success story both because live barriers are effective in controlling soil erosion where sloping land is cultivated and because we understand why. Anthony Young (pp 2-4) identifies increased infiltration of water under hedgerows as the major reason for their effectiveness, leading to conservation of water as well as soil. Dennis Garrity *et al.* (pp 5-7) illustrate the maturity of current understanding of hedgerow effects by stressing the importance of soil redistribution within alleys between hedgerows. While this has the beneficial effect of creating terraces, it may also cause yield declines in parts of the alley from which soil is scoured. This is a particular problem on acid soils, that are deficient in phosphorus, but farmers have developed strategies to reduce negative effects, including strategic placement of hedge prunings or other fertilizers on affected areas. Such adaptation of contour hedgerow technology by farmers forms the core of several papers in this issue that concentrate on adoption. Anna Lawrence (pp 11-13) reports on participatory research in Bolivia where browsing of hedges by livestock is an important issue while Hellin and Larrea (pp 17-20) in Honduras found that farmers were as concerned about the productivity of species used in live barriers and their competitiveness with crops, as with their effectiveness in conserving soil. This is echoed by McDonald *et al.* (pp 21-25) who report farmers introducing species which produce short term economic return. While labour availability and tenure are repeatedly cited as key determinants of farmer adoption of soil and water conservation measures, Sam Fujisaka (pp 8-11), considering experience from many contrasting locations, proposes that contour hedgerows are only likely to be adopted by farmers where soils have a high potential productivity worth conserving and human population density is high, precluding extensive forms of land use. While there is a growing consensus about the effectiveness of contour hedgerows and their ready adaptation by farmers to local conditions and priorities where they are appropriate, Rita Gardner and Kevin Mawdesley (pp 25-29) warn of 200-fold differences in estimates of soil erosion in the Himalayan region. It is not known to what extent these differences reflect real variability in how much soil is eroded as opposed to artefacts of the measurement methods used. This makes comparability of measurement techniques, and scaling procedures from fields to whole hillsides, key issues for further development.

This special issue of *Agroforestry Forum* has been funded jointly by the Natural Resources Systems Programme and Forestry Research Programme of the UK Department for International Development (DFID) for the benefit of developing countries. The views expressed are not necessarily those of DFID.

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Anthony Young

The effectiveness of contour hedgerows for soil and water conservation

Hedgerows planted at 4-8 m between-row spacing, parallel with the contours, provide a means for soil and water conservation under annual cropping. Experimental evidence shows that this system is technically effective on slopes of up to 20%. The rate of infiltration is considerably increased under the hedgerows, hence the system conserves water as well as soil. Experience with adoption by farmers is variable, but at the least, no worse than for earlier conservation projects. Active farmer participation in the extension process is essential. Overall, the contour hedgerow system provides a viable alternative to conventional methods of soil conservation. For steep slopes, further research is needed.

Introduction and context

A new approach to soil conservation has supplemented, and to some degree replaced, former methods based on earth structures (bunds, terraces, etc.). In this approach, there are two main elements: the use of biological methods, and their application through the active participation of farmers. Agroforestry offers major opportunities in both these respects: through the use of trees and shrubs in conservation, and by providing an element of production (e.g. of fuelwood, fruit or fodder) from the use of this method.

Agroforestry offers opportunities to put into practice the biological approach to soil conservation

Trees and shrubs can be employed in soil and water conservation in two ways, supplementary and direct. In supplementary use, trees are added to conventional conservation structures, such as terraces, bunds or grass strips. The trees serve to stabilize earth structures, and to supply production from the land which these occupy.

In direct use it is the trees themselves, as a means of biological control, which are the main agent for checking erosion and runoff. Two main agroforestry systems are employed: multistrata systems and contour hedgerow systems. Well-managed dense multistrata systems (including perennial crop combinations) are seen by general observation to be so highly effective in checking erosion - largely through their ground surface cover of litter - that there have been few experimental measurements. They are, however, ecologically limited to more humid climates and areas of perennial cropping.

On slopes of up to 20%, the contour hedgerow system leads to spectacular reductions in erosion

For conservation of systems with annual crops, the principal method is the contour hedgerow system. This appears to have originated in the 1970s on Flores Island, Indonesia, but became more widely known through demonstrations and projects in the Philippines from 1978 onwards. Single or double hedgerows (with inter-plant spacing of about 25 cm) are planted parallel with the contours, between which are the cultivated alleys. The species most widely employed have been *Leucaena leucocephala, Gliricidia sepium, Senna (Cassia) siamea* and *S. spectabilis*, although there is opportunity to widen this range, possibly including fruiting plants such as guava.

The between-hedgerow spacing is generally 4-8 m, although the requirement of following the contours should mean this varies. In a trial at Machakos, Kenya, double rows (25 cm apart, stems offset) at 8 m spacing were found to be no less effective than single rows at 4 m, and might be expected to be more acceptable to farmers (Kiepe, 1997a).

Reviews of the contour hedgerow system, together with other methods of soil conservation through agroforestry, have been given by Young (1993), Kiepe and Rao (1994), and Young (1997, chapter 3), this last with additional details and references.

Technical efficiency

For an agroforestry system to achieve its aims, there are two requirements: it must be technically efficient, and adopted by farmers.

There have been at least 15 experimental studies of contour hedgerows (Table 1). To be technically efficient, a system of soil conservation should reduce erosion to well below its rate on land without the system, and below the commonly accepted 'tolerable' level of 10 t ha^{-1} per year. On both these criteria, the system is highly effective on gentle to moderate slopes, less so on steep slopes. On land below 20% slope, all nine trials show erosion at under 10 t ha^{-1} per year, whilst the reduction factors (erosion without conservation divided by erosion with hedgerows) range from 6 to over 30. Two storm events in a trial at Machakos, Kenya, demonstrate this effectiveness in spectacular fashion. Without hedgerows, soil loss was 34 and 24 t ha^{-1} in the first and second storms; with hedgerows, it was reduced to between 5 and 0.2 t ha^{-1}.

On steep slopes, over 25%, the evidence is less clear-cut, only two of the six trials being clearly successful. The problem is that to achieve conservation, the hedgerows need to be some 2 m apart, and this does not leave enough room for cropping. An exception is what can be called 'the Malawi system'. In a trial at Ntcheu, Malawi, maize was grown in rows at its normal spacing and *Leucaena* hedgerows, pruned low, planted between every row, giving an inter-hedgerow spacing of only 90 cm. This has been continued to give good maize yields for six years, whilst adjacent control plots have been reduced to stony rubble (Banda *et al*., 1994). Further trials of this system are urgently needed.

For most trials, data on crop yields refers only to the early years. The limited evidence shows that yields are neither significantly higher nor lower than those on control plots during this period. Demonstration plots established on the ICRAF field station in Machakos, Kenya, in 1983, with a low fertilizer input, are still (1997) producing sustained crop yields (Kiepe and Young, 1992). No trial has yet substantiated a yield improvement in later years deriving from soil conservation.

Reasons for effectiveness

It was at first thought that the system functioned through a 'sieve' mechanism, soil being held up by the hedgerows whilst water flowed through them. This is supported by the micro-terraces, about 50 cm high, which quickly build up at each hedgerow. If this were the only process, however, water flow would not be reduced. In fact, reductions in runoff, smaller than for soil loss but still substantial, have always been observed. The mechanism must therefore be that infiltration is being increased. This has been confirmed by measurements at Machakos, Kenya, using a drip infiltrometer. During the dry season, the steady rate of infiltration was 135 mm h^{-1} beneath the hedgerows compared with 44 mm h^{-1} in the cropped alleys; values during the wet season were 8-11 and 69 mm h^{-1} respectively (Kiepe, 1995a, 1995b). Improved soil organic matter and the physical check to flow by the hedge stems may be a contributory factors, but the main cause is probably flow down root channels of the hedge.

The main process involved is a higher rate of infiltration beneath the hedgerows; hence the system conserves water as well as soil

Another favourable feature is that contour hedgerows occupy a small proportion of the land surface, typically 10-12%, compared with 15-20% for earth structures or grass strips. There is sometimes a problem of skewed crop distributions, highest on the lower parts of the alleys where soil, nutrients and water accumulate, with lower yields on the upper parts.

Management

The hedgerows must be pruned before planting the crop, and at least once during the growing season. Plants which die should be replanted the following year, although farmers may not always do this. Multiple strips, each of a hedgerow parallel with a strip of vetiver or other grass, are a possible variant.

Experience with adoption by farmers has been variable

There are three alternative treatments for the prunings: placed along the hedgerows, spread over the alleys, or harvested. Spreading the prunings as a mulch across the alleys is the most effective for control of erosion; it also provides nutrients from litter decay, although hindering cultivation. Since farmers will often wish to harvest the prunings as fodder it is fortunate that the system still checks erosion, if less effectively, when this is done.

Table 1. Experimental evidence on contour hedgerow systems. For sources, see Young (1997, p.71).

		Erosion (t ha^{-1} yr^{-1})		
Country	Slope (%)	Control	Contour hedgerows	Reduction factor
Nigeria	7	8.75	0.95	9
Indonesia	12	103	9	11
Sri Lanka	5-13	11.7	1.3	9
Kenya	14	6.4	0.2	32
Peru	15-20	79	5.8	14
Indonesia	8-18	57	10	6
Philippines	14-19	127	3	42
Philippines	17	141	2.8	50
Philippines	18	194	3.4	58
Rwanda	28	304	14-44	7-22
Philippines	25-40	36	2	18
Malawi	42	44	1.6-2.5	18-27
Indonesia	45	n.d.	38	-
Thailand	20-50	120	65	2
Rwanda	50-60	35-90	36-92	1-2

For steep slopes, further research is needed, especially trials of the 'Malawi system' of very closely spaced hedges

Do farmers accept the system?

There is certainly additional labour required for establishment of the hedgerows, and for their repeated pruning. Experience with adoption by farmers has been variable. A fair proportion, possibly half, of the hedgerows on Flores Island are still present. The major trial ground has been the Philippines, where non-governmental organizations and development projects have been advocating the system since 1980. There have been some successes, notably on an aid project in Visayas which placed much emphasis on farmer participation. However, a recent review concluded that the system was not yet sustainable: after initial adoption, a substantial proportion of farmers later abandon it (Fujisaka and Cenas, 1993). A reason for non-adoption was demonstrated in a study which employed the SCUAF model (Young *et al.*, in press) to simulate crop yields over 25 years, then applied cost-benefit analysis. Contour hedgerows were compared with continuous cropping and with a fallow system. The hedgerow system gave higher yields, and higher net returns, from Year 5 onwards, and on standard project cost-benefit criteria it is clearly superior. However, these higher returns "lie beyond farmers' limited planning horizons" (Nelson *et al.*, 1997).

Conclusions

On the basis of technical effectiveness, on gentle to moderate slopes (up to 20%), the contour hedgerow system provides a viable alternative to conventional methods of soil conservation. For steep slopes, further research is needed, especially trials of the 'Malawi system' of very closely spaced hedges.

Experience with adoption by farmers is variable, but certainly no worse than that for conventional soil conservation. The relatively small area occupied by the hedges, coupled with the flexible options to obtain some harvest from them, increase the attractiveness. Overall, the system can now be recommended on all but steep slopes, provided that extension work is based on close cooperation with farmers, permitting them to adapt the system to their perceptions and requirements.

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Dennis Garrity, Marco Stark and Agustin Mercado

Rapid soil redistribution within alleys: why simple extension models for contour hedgerows may not be appropriate

Rapid redistribution of soil often occurs within the alleyways of contour hedgerow systems, resulting in quite dramatic yield reductions in the upper zones. Is this a threat to the sustainability of contour hedgerow systems? Recent work suggests that while it is a threat on strongly acidic soils, it ought to be a manageable one. Farmers who have encountered scouring have developed practical ways of coping. These are currently being validated experimentally. Robust management solutions will depend on a more fundamental understanding of the processes governing fertility resilience in contour hedgerow systems. Emerging models that include landscape aspects will assist us in achieving it.

Introduction

When farmers install contour hedgerow systems to help sustain annual cropping on sloping land they face many unusual management challenges. They must cope with the increased labour demands to prune and maintain the hedgerows. They may also need to make adjustments to minimize competition between the hedgerow species and the associated food crop. And often, they encounter accelerated soil deterioration in the upper zone of their alleyways. This soil deterioration is caused by the redistribution of topsoil within the alleyway, from the upper to the lower zones, as terraces naturally develop.

This contribution briefly reviews the nature of this scouring-deposition effect, discusses the challenges it poses to the sustainability of contour hedgerow systems, and dwells on why it has tended to be overlooked in the past. We examine how farmers react to the problem, and discuss the practical solutions that our preliminary research has identified and attempted to validate. We suggest how extensionists can guide farmers in awareness of the problem and applicable solutions. And finally, we suggest needed directions for further research to ensure that the phenomenon is well-enough understood that robust ways of coping with it can be developed for a wider range of environments.

Soil redistribution within alleyways

Rapid soil redistribution within the alleyways of contour hedgerow systems was viewed very positively in the early literature on hedgerow research and extension. Biological barriers were very effective in creating permanent bunds. The land between the barriers may begin to flatten out within just a few years. The process leads to a reduction in slope and creates front-facing terraces. Thus, terrace development occurs as a by-product of normal tillage within the alleyway. There is no additional work and expense for soil excavation. The visual effect was often quite striking (Fujisaka *et al.*, 1995; Sajjapongse, 1992). The reduction in soil loss was typically also striking, often in the order of 50-90% (Garrity, 1994).

Yield decline

We began to observe serious upper-alley yield declines within a few years of hedgerow establishment in a number of on-farm trials in Claveria, Philippines in the late 1980s (Garrity, 1994). The soil was an Oxic Palehumult which had physical and chemical properties fairly typical of the strongly acidic, low phosphorus status of some 186 million hectares of sloping upland soils in Southeast Asia (IRRI, 1986). At first it was assumed that the effect might be due to more intense competition exerted by the hedgerow toward the crop in the upper alleyway compared to the lower alley zone. Root barrier studies (Solera, 1993), soon discounted this hypothesis. However, soil analyses of affected fields consistently showed that soil organic carbon, total N, and available phosphorus had declined substantively in the upper zones, while they increased in the lower zones (Agus, 1993; Samzussaman, 1994; Garrity *et al.*, 1995). The Claveria farming system was one of double-cropping of maize using animal draft for tillage. Similar soil spatial changes were reported in hand hoe cultivation systems in Uganda (ICRAF, 1994) and on an Ustic Kandihumult in Thailand (Turkelboom *et al.*, 1993).

Soil deterioration is caused by the redistribution of topsoil within the alleyway, from the upper to the lower zones, as terraces naturally develop

Where animal or hoe tillage is practiced several times in a year for weed management, the redistribution process is greatly accelerated

As the picture emerged of how serious these upper-alley yield declines could be, and that they most likely resulted from the degradation of the upper-alley soil environment, we grew very concerned that the phenomenon might call into question the sustainability of cropping in contour hedgerow systems at least on some major classes of soils in the tropics (Garrity, 1994). Were hedgerow systems causing more problems than they would presumably solve? Why had the effect gone unreported until recently? How would farmers react to it? And, above all, how could it be avoided or overcome?

We now suspect that previous studies on hedgerows may have not observed the

Yield increases on the lower zones apparently offset the declines in the upper zones

phenomenon for two reasons: most of the alley cropping work done on slopes (at least in Southeast Asia) was done on young, deep volcanic soils with moderate to high available phosphorus levels (e.g. MBRLC, 1988). Topsoil scouring in these soils would not be expected to degrade the soil environment in the upper-alley zones to the extent that it would in strongly acidic, P-deficient soils. However, sloping soils with these latter constraints are much more dominant geographically. The frequency of tillage is also a factor. When minimum or zero tillage is practiced the rate of soil redistribution is much slower. Unfortunately, reduced-tillage is often difficult for smallholders. Where animal or hoe tillage is practiced several times in a year for weed management to accommodate intensive cropping systems, as is commonly observed, the redistribution process is greatly accelerated, and soil degradation proceeds more rapidly.

Farmers solutions

Many farmers had developed their own practices to overcome the scouring problem

How do farmers react to the problem? Fortunately, we were in a good position to answer this question. In the vicinity of the Claveria research site, scores of farmers had gained experience with the installation of hedgerows on their farms during the late 1980s and early 1990s. We surveyed a representative group of 30 smallholders who had been practicing contour hedgerow farming for up to seven years. Most adopters had observed reduced crop yields on their upper alleyways. Interestingly, however, they did not perceive the scouring effect to be a serious constraint, or a permanent one (ICRAF, 1997). They noted yield increases on the lower zones that apparently offset the declines in the upper zones (Figure 1). They were confident of the satisfactory soil conservation effects of biological terracing, and pointed out that scouring also occurred on the whole of the upper part of unhedgerowed fields. Their perception was that the investment in the buffer strip system seemed to increase yields over the whole field. A telling finding was that more than half of the respondents estimated that installation of the hedgerow system increased their land values by more than 50%.

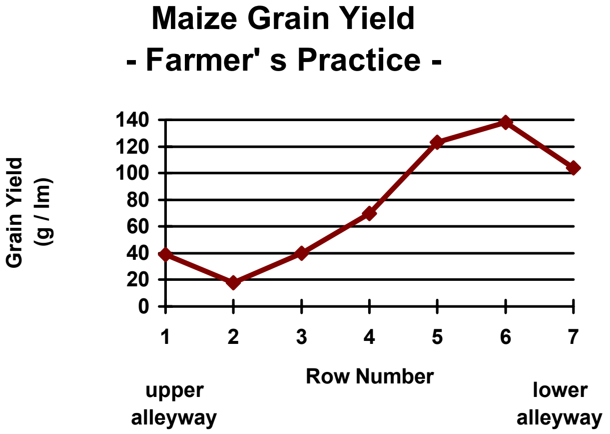

Figure 1. Typical maize grain yield per linear metre across a single alleyway under farmer management on an acid upland soil (mean of three replications). Claveria, Philippines.

Many farmers had developed their own practices to overcome the scouring problem. The most common of these was to apply more mineral fertilizer on the upper alleyway zones than on the lower zones (usually up to double on the upper zone). Also, farmers frequently applied hedgerow prunings selectively to the uppermost zone. A few even brought in additional biomass from off-field for the upper zone, or scraped soil from the bund down onto the upper alleyway. We have been conducting trials with hedgerow farmers during the past few years to validate these practices and to try to understand the underlying processes involved in rehabilitating the soils in upper alleyways. The results have tended to confirm the utility of skewing higher fertilizer applications toward the upper alleyway: these increase maize yields in these zones to levels similar to those in the lower zones. It appears, however, that uniform fertilizer applications give similar overall yields on a whole alley (or field) basis when applied at moderate levels.

Future developments

What is the key to sustaining good crop yields as terraces develop behind vegetative buffer strips? In the short term, it appears that the importation of nutrients through manures and/or fertilizers containing adequate amounts of crop-available P, are essential in maintaining yields. In the medium-term, however, we hypothesize that rebuilding soil fertility in the upper alleyways depends on replenishing the soil organic matter levels in the topsoil of the scoured zones. More and longer-term field research is needed to validate these presumptions on strongly acid soils, and upon a much wider range of sloping lands in the tropics where farmers cope with the challenges of producing annual crops continuously. We are impressed (indeed fascinated) with the apparent resilience of the intensively managed ultisols and oxisols of northern Mindanao. However, we suspect that the shallow, calcareous soils typical of much sloping farmland of Southeast Asia will not be as forgiving as the deep, well-structured soils on which we have worked.

To be adequately predictive we will need to understand the fundamental processes governing soil fertility resilience in contour hedgerow systems. Modelling these systems will be crucial to sorting out the complex interacting processes that operate on landscapes being transformed into terraces. Conventional crop and agroforestry simulation models have not yet been developed that adequately incorporate the key landscape-level issues that need to be addressed. Currently, however, the model on Water, Nutrient, and Light Capture in Agroforestry Systems (WANULCAS) is being adapted to these spatially zoned systems (van Noordwijk, 1997, pers. comm.) We look forward to rapid progress in this area in the near future.

Contour hedgerow systems continue to be adopted by increasing numbers of farmers in the vicinity of the research site in northern Mindanao. We estimate that some 500 farmers are now practicing the system. Many adopted spontaneously through a farmer-to-farmer diffusion process. An important factor in the spread was the shift to hedgerows composed of natural vegetative strips (NVS) in lieu of the pruned tree hedgerow systems conventionally recommended by extensionists throughout the region. NVS systems proved much more popular because they dramatically reduced the labour requirements for installation and maintenance, while their effectiveness in reducing off-field soil loss was superior (Garrity, 1994).

Natural vegetative strips systems proved popular because they dramatically reduced labour requirements while their effectiveness in reducing off-field soil loss was superior

NVS systems do not fix and cycle nitrogen, as is attributed to hedgerows of leguminous trees. But in a P-limiting environment, tree-based hedgerows are themselves not effective in cycling adequate amounts of P to meet crop demand, and are therefore unable to sustain crop yields. Increasingly, the future for contour hedgerow systems looks certain to shift to low labour alternatives like NVS, with soil fertility being maintained by nutrient importation. The need for nutrient importation to balance crop off-take is not different than in most other types of agricultural systems, except that these systems make sustainable annual cropping possible on steeply sloping lands prone to severe erosion. Thus, they're not ideal, but they are pretty remarkable nonetheless.

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Sam Fujisaka

Sense and nonsense: contour hedgerows for soil erosion control

Researchers concerned with sustainable agriculture on sloping lands have considered contour hedgerows an appropriate innovation for reducing soil erosion. Hedgerows, once established, use erosive forces to naturally form terraces, reduce soil and water run-off, and eventually form stable parcels. Problems include hedgerow-crop competition, costs of establishment, and space occupied. This article makes two propositions. First, that even when these technical problems are solved, contour hedgerows 'make sense' only where most agricultural lands are sloping and soil erosion rates are high, population is high and the land frontier is closed, and where native soil and land productivity are at least moderate. Second, that inappropriate targeting of the technology has caused an observed lack of farmer adoption of contour hedgerows in some circumstances.

Introduction

This article is based on results of farmer-participatory research in the adaptation and adoption of contour hedgerows for soil erosion control in northern Mindanao, Philippines (conducted from 1987 to 1993), and on more qualitative evaluations of their adoption and non-adoption in other areas of sloping agricultural lands. Research showed that contour hedgerows substantially reduce soil erosion loss rates; but problems associated with hedgerows included crop-hedgerow competition, the space occupied by the hedgerows, and labour for establishment. Although farmer participatory research developed a means of addressing these problems, which led to a moderate level of adoption, a wider adoption did not occur until changes in population and the land frontier took place. This result and more current work in other upland sites led to further thinking about a hypothesis regarding adoption and the sense or nonsense associated with contour hedgerows for soil erosion control.

Wider adoption did not occur until changes in population and the land frontier took place

Results of farmer participatory research in the Philippines

Farmer participatory research in Claveria, Mindanao, Philippines, started with farmer-identification of declining crop yields as a problem and soil erosion as one of the causes. Some 60% of cropped area was on slopes of greater than 15%; annual rainfall averaged 2200 mm; and land preparation for rice, maize, and cassava by animal-drawn plough all contributed to losses of the Oxic Dystropept clays to silty clay loams of about 200 t ha^{-1} yr^{-1}. We facilitated a farmer-to-farmer exchange in which a small group of concerned Claveria farmers learned to: use an A-frame to establish contour lines, form bunds along the contour using plough and shovel, and then plant *Gliricidia sepium* and *Pennisetum purpureum* hedgerows on the bunds.

Farmers developed and adopted the use of weedy strips

These hedgerows manifested problems and allowed for substantial farmer-researcher collaborative problem solving. After *P. purpureum* proved too competitive with rice and maize, farmers tried other hedgerow species including locally available *Flamengia congesta*, *Helianthus anuus*, and *Senna (Cassia) spectabilis*. *G. sepium* was intended for use as a green manure, but was discarded: farmers empirically knew that phosphorus rather than nitrogen was limiting and soil organic matter was relatively high in most fields. The bunds were found to be unnecessary such that initial ploughing and shoveling were not done and labour input was, therefore, decreased. The original double hedgerows of trees and grass had also occupied substantial space.

Over time, farmers (with researcher collaboration) developed and adopted the use of natural vegetative strips. A contour line was laid out using an A-frame, and a narrow width along the marked line was simply left untouched when farmers ploughed the alley. Weeds in the unploughed strip were allowed to grow and required only periodic pruning. The result required little labour for either establishment or maintenance and occupied little space. A solid hedgerow formed of combinations of naturally regenerated species including *Pennesitum polystachon, Paspalum conjugatum, Borreria laevis, Ageratum conyzoides*, and *Chromolaena oderata*. Terraces could be formed and soil erosion losses effectively reduced to some 20 t ha^{-1} yr^{-1} (Fujisaka, 1989, 1993; Fujisaka *et al.*, 1994). Later research at the site also confirmed that the weedy strips required little labour for pruning, did not compete with adjacent crops, were efficient at reducing soil loss, and did not add to weed problems in the associated annual crops (Garrity, 1997).

Despite these advances and some assistance given to the process of farmer-to-farmer technology transfer, numbers of adopters remained modest - some 60-70 farmers by 1993 when our research terminated. Monitoring revealed that some farmers were fallowing fields with contour hedgerows, leading to an initial hypothesis that the land frontier would have to be closed for farmers to adopt a more intensive system than open field management (Fujisaka *et al.*, 1994).

Other sites

Sites where little or no adoption of contour hedgerows has occurred

Adoption of contour hedgerows has been poor at most sites where promoted, including in Honduras, Nicaragua, Vietnam, and Thailand where the Centro Internacional de Agricultura Tropical (CIAT) conducts collaborative research on improved crop and natural resource management. Sites are described below.

1. **Yorito, Yoro, Honduras, and San Dionisio, Matagalpa, Nicaragua**. Farmers cultivate maize followed by beans on a range of slopes. Rainfall is low (1 000-1 300 mm at both sites). Farmers use herbicides and little tillage; most plant along the contour, and periodically fallow some of the steepest fields. Soils can be moderately deep on all but the steepest slopes. Although since the early 1980s, various projects at each site have worked to introduce contour hedgerows for soil erosion control, soil losses are probably not more than 30-40 t ha^{-1} yr^{-1} on steeper fields and little, if any, non-project spontaneous adoption of hedgerows has taken place.

2. **Cassava producing areas of Thailand and the Red River delta of Vietnam**. CIAT conducts collaborative farmer participatory research with Thai cassava growers in an area where fields are large and gently rolling. Per hectare and per field soil losses are relatively small (albeit the extensiveness of cassava production means that aggregate losses for the area may be high). Vietnamese farmers have lowland rice and a mix of carefully tended upland crops. Most upland crop fields employ contour ridges and furrows, and many have been bench terraced (given easy-to-manage, light soils). Soil losses do not appear to be substantial. Despite farmer participatory research on soil erosion control, adoption of contour hedgerows has not occurred in these Asian sites.

These cases are not uncommon. Research on, introduction of, and little farmer adoption of contour hedgerows has taken place on the eastern slopes of Madagascar, in various locations in Indonesia, northern Thailand, the Philippines, Laos, Ecuador, and Peru (and probably elsewhere).

Sites where adoption of soil conservation measures has occurred

The above examples do not imply that farmers do not practice soil conservation. The Central American farmers conserved soil by employing minimum tillage (adopted because herbicides were less expensive than hired animals and hired manual weeding) and contour planting. Vietnamese farmers manually bench terraced some of their light soils and used contour ridging.

Adoption of contour hedgerows has been poor at most sites where promoted

Careful farmer conservation of soils in sloping upland agricultural areas can be seen elsewhere. Some examples are: in the Diang Highlands of Java, Indonesia, where vegetable farmers carefully tend steep fields of volcanic soils; in Machakos, Kenya, about which the book *More People, Less Erosion* was written (Tiffen *et al.*, 1994). Also in eastern Ethiopia where, again, relatively productive soils on sloping lands combined with high population numbers led to widespread indigenous soil conservation. These experiences and observations lead to a rough hypothesis regarding adoption of soil conservation measures in general and of contour hedgerows in particular.

Conclusions

A tentative hypothesis. Farmers adopt conservation measures only under certain conditions. These are where soil erosion is a problem, where erosion affects most farmers and fields, or where soils are from moderately to highly productive. Another condition is where population has increased to the extent that: a) shifting fields is no longer physically or economically feasible; and b) sufficient labour is available to invest in conservation measures.

As a guess to provoke discussion, a minimum mean of 80 t ha^{-1} yr^{-1} might qualify soil erosion as a problem that farmers would take measures to address.

Such soil erosion needs to affect most farmers and fields. In the Diang Highlands and eastern Ethiopia, as in Claveria, most cultivated land is sloping; and alternatives such as lowland rice do not exist. Indeed, early non-adopters in Claveria had significantly higher proportions of flatter lands (and greater off-farm income) than did adopters.

Soils need to be worth saving, as in the Diang Highlands. Conversely, adoption of contour hedgerows would be unlikely where soils pose major constraints such as in the limestone areas of southern and East Java where soils are poor, shallow, and often rocky.

Population needs to have increased to the point where farmers cannot profitably retain extensive practices; especially shifting parcels (i.e., from shifting cultivation to tenanting of new fields by owners as was documented in Claveria). Once agriculture is sedentary, the same population provides the labour pool needed for investments in intensified resource management.

The hypothesis can also be expressed in a four-cell matrix with sloping agricultural areas with lower population and open

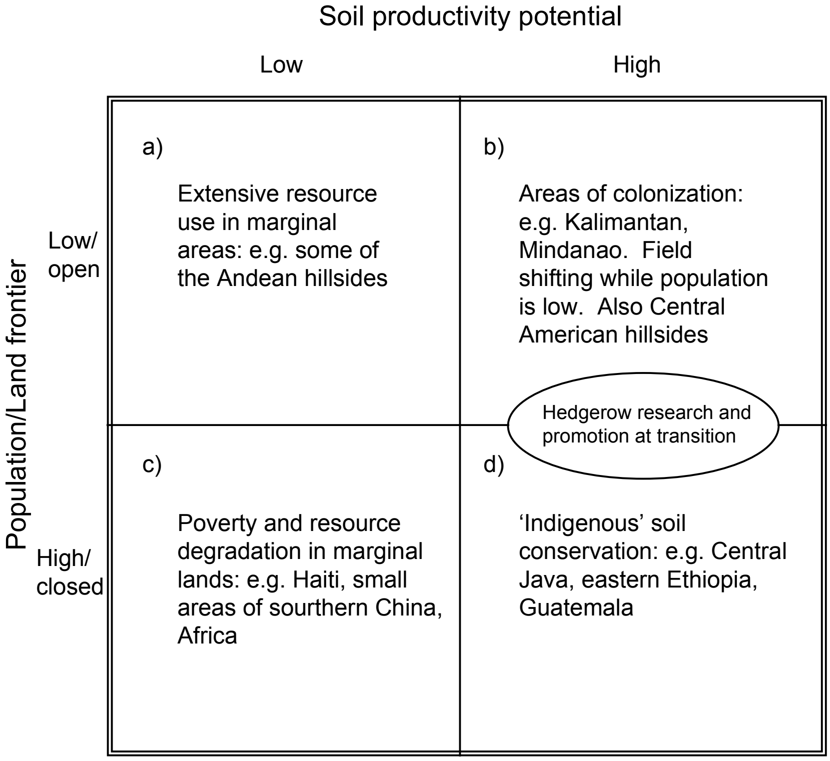

Figure 1. Sloping agricultural lands matrix.

frontiers versus higher populations and closed frontiers on one axis and low versus high soil productivity potential on the other axis (Figure 1). Although contour hedgerows as a way to reduce soil erosion have been promoted all over the globe, there may be only a limited subset of upland areas where farmers can and will adopt soil conservation measures.

Nonsense. Extensive resource exploitation is expected and observed in areas where soils are marginal and populations are low (Figure 1, cell a: e.g. large portions of the Andean hillsides). Soil conservation measures such as contour hedgerows are largely unnecessary and adoption would be highly unlikely.

Where soil resources are more favourable and population is low, extensive agriculture that includes fallows and different forms of field shifting are practiced (Figure 1, cell b). As will be further discussed, these are usually dynamic frontier areas attractive to migrant settlers: e.g., East Kalimantan and parts of Mindanao. Farmers' strategies are rational despite the fact that soil erosion control on particular fields would make technical sense.

Poverty and resource degradation have been associated with marginal soils and high population. Outside of my experience, parts of Haiti, southern China, and selected areas of Africa have been suggested as falling within this category (Figure 1, cell c).

Sense. Farmers likely will have already developed soil conservation measures where soils are relatively productive and where population is high (Figure 1, cell d). Again, examples include volcanic slopes in Java, some of the intensively farmed hillsides of Guatemala, eastern Ethiopia, possibly areas such as Machakos in Kenya, and sloping areas of some of the inter-Andean valleys such as Cochabamba, Bolivia.

Where, then, does it make sense to promote contour hedgerows and other soil conserving innovations? Only in the more favorable areas where erosion is a problem and population is reaching the point where extensive forms of land management are no longer possible. Recent trends in Claveria lend support to the hypothesis. Adoption of what have been renamed 'natural vegetative strips' has substantially increased with increased migration to the area and greatly reduced possibilities for farmers to tenant or rent fallowed parcels (Dennis Garrity and Sushil Pandey, 1997, personal communication).

All of this suggests that research and extension should cease promoting contour hedgerows where certain conditions exist. These are where erosion is not a sufficiently serious problem, or where farmers have already conserved soils using other measures. Also in marginal, over-populated areas where there is little local ability to invest and where soils remain poor even if not lost to erosion (and where other structural changes are more urgently needed), and where low population and land availability in more favourable areas makes extensive practices sensible. Instead, resources shoul be focused on favourable frontier areas experiencing a transition in which populations are rising and where farmers see new needs for soil conservation and contour hedgerows.

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Contours, crops and cattle: participatory soil conservation in the Andean foothills, Bolivia

Farmers in Santa Cruz have more soil conservation knowledge than scientists have supposed, because they respond to fertility and moisture problems rather than the externally-identified erosion problem. Indigenous practices include contour-related management. Participatory trials incorporate contour hedgerows and farmers' attitudes are becoming more favourable as they see the effect, but the focus on management of cropped land does not address the wider causes of land degradation.

Introduction

The temperate valleys of Santa Cruz, Bolivia are a mountainous, semi-arid zone, where crops are produced on lower (but often steep) land nearer to homes, while extensive cattle and sheep farming is practised on land further from the community. Livestock are an important contribution to status and security; sales are rare and investment in improvement is minimal. In some parts of the Valleys rangeland is owned by a group who use the area as one single undivided range. Those who have more cattle benefit more from this system, which is thereby perceived to encourage overstocking, overgrazing and therefore soil erosion. No study has previously been made of farmers' soil and water conservation (SWC) practices, and projects have focused on introducing technologies to the cropped lands in the more humid valleys.

A participatory project aims to identify relevant knowledge and practices in the temperate valleys (amongst farmers and institutions), and to facilitate the use of this knowledge by farmers, in experiments of their own design on their farms. The diagnostic phase has shown the interaction of social and technical factors in farmers' soil management practices (Lawrence *et al.*, 1997). Information was collected through group discussions, semi-structured interviews, field visits and PRA tools including mapping and matrix ranking (Lawrence, 1997). During research-planning workshops, farmers produced farm plans for their own SWC trials, taking into account their responses to introduced technologies such as contour hedgerows and cover crops. Drawing on this work, this article reflects on the principal features of farmers' own practices, and the potential for assimilating new technologies into the farming system in the temperate valleys.

Participatory approaches bring together different people's knowledge

Farmers' soil conservation practices

Farmers claim that they have not traditionally done anything to conserve soil. Soil erosion is not a problem which many farmers identify; group problem ranking exercises show that loss of productivity, and decreasing water and soil humidity, are higher priorities. In line with this, farmers are using a range of practices to conserve soil fertility, principally incorporation of crop residues and recycling of residues through livestock grazing. Ranking soil conservation practices, and listing sources of information with village groups showed that some of this knowledge was passed on from parents and grandparents. Farmers' knowledge is undervalued if these sources of ecological understanding are ignored.

Farmers' soil and water conservation knowledge is undervalued by both farmers and scientists

Individuals are beginning to innovate as they increasingly recognise soil erosion problems. Reduced burning, and leaving fallow or crop residues in contour lines, are the most common practices, especially in the older communities. Some farmers have developed a range of practices, such as cutting (not burning) the weeds in orchards, and leaving them in contour lines, or using them to slow runoff in gullies; planting fruit trees along the contour; and mulching around fruit trees in cropped fields. While several indigenous practices recognise the importance of contour barriers, farmers do not refer to contours, but talk about planting 'across the slope'. Social responses are following more slowly, but some groups have decided to delimit individual property within the rangelands, which allows them to fence and manage it more sustainably. Two communities have banned burning, and all have taken community action to protect water sources.

Innovation is easiest on individually-owned cropland

Contour hedgerows are less attractive to women, who are more interested in livestock and fruit

Contour hedgerows only address part of the problem in the temperate valleys

Introduced technologies in neighbouring areas

No extension organisation or NGO has attempted to introduce soil and water conservation technologies in the area, but in the lower more humid part of the Valleys zone, several NGOs have promoted contour barriers (both hedgerows and slow-forming terraces based on dead material), as well as cover crops in orchards. Farmers who have experimented with these technologies discussed them with farmers from the semi-arid zone, during the research-planning workshops. This farmer-to-farmer communication was identified as the most important feature of the farmers' research-planning process.

Farmers incorporating contour hedgerows

Farmers are incorporating outside technologies and adapting them into their systems. Contour hedgerows are being used in two ways. Some farmers are hosting on-farm trials managed by scientists (Sims, this issue). Others have chosen to include them as elements of their own experiments, as a result of the participatory research-planning workshops. The scientist-managed trials are less than one year old, but already some interesting reactions and changes in attitudes have taken place among host farmers and their neighbours. One farmer had tried contour hedgerows before with an NGO, but eradicated them because they interrupted ploughing; the current trials initially provoked the same complaint, as well as doubts about the forage quality of the species used. The cattle grazed trees and grasses to the ground, but the barriers still visibly held the soil and this impressed other farmers enough for them to want to try them out. Another farmer changed the spacing of the hedgerows before establishing them, because he wanted the space to turn his oxen. There is now a distance of about 10 m between the hedgerows, instead of the 6 m spacing which his brother had found difficult.

Having seen the resistance of the hedgerows to heavy grazing, farmers also point out that the hedgerows are starting to build up soil on the uphill side. More importantly from their point of view, it was clear that tree hedgerows are helping to retain soil moisture. While most of the soil had dried out after rain a few days earlier, there were still damp patches around the base of the young trees.

In one community where forest clearance is still happening, there has been little enthusiasm for participatory trials of hedgerows. In the other communities however several farmers have included hedgerows in their farm plans, usually only one or two barriers across their fields. Joint evaluation with scientists will be important to find out if these wide spacings fulfil farmers' objectives and appear to have an effect on soil conservation.

Gender differences

The views of women farmers are not often sought by researchers or extensionists in the zone, but their knowledge has proved to be distinct and valuable to the project. They professed to know nothing of soil and water conservation, but proved knowledgeable about the role of organic matter in the soil, and the impact of changes in the farming system. Women are mainly responsible for livestock management, and fruit production in the orchards near the house. They showed less interest than men in the contour hedgerows, and felt it was a higher priority to improve the soils in the orchards by sowing cover crops.

Priorities for participatory research in SWC

Technicians say that farmers have done nothing to prevent soil erosion. This criticism stems from their perception of the problem; farmers have not established barriers to soil loss, but they do have practices to maintain soil fertility and moisture. The implications are that farmers may be doing more than is apparent to prevent soil degradation, by addressing a different problem from that identified by outsiders. This may mean that a technology is incorporated for reasons other than those intended by the development agent; for example, contour hedgerows intended as barriers to soil erosion interest farmers primarily because they maintain soil moisture.

Potential for contour hedgerows in the temperate valley farming systems

The attitudes of participating farmers and their neighbours to formal on-farm trials of contour hedgerows has changed significantly over the last eight months, highlighting the importance of interacting with farmers and monitoring their views throughout the research process in order to understand how interest in a technology develops. Nevertheless, there are social factors in their acceptability: contour hedgerows appeal more to men than to women, and are not acceptable where the benefits are not felt by the person establishing them, for example where land is shared between farmers with different numbers of cattle, or tenure is only short-term. Livestock are an important component of the farming system and will be given priority when grazing the land. Fencing is only an option for richer farmers and scientists, so alternatives have to be found if contour hedgerows are to be used compatibly with livestock. These could include using unpalatable species, but most farmers designing their own experiments choose forage species for the contour hedgerows. Group decisions on livestock management may be necessary, and for this it would be important to involve women more explicitly than has been the tendency to date.

Conclusion

Constraints to contour hedgerow adoption include lack of information (and farmer-to-farmer contact), as well as scarcity of planting material. By overcoming these constraints, farmers are interested in adapting hedgerows into their production systems. Although scarce, labour is not a discouraging factor at this stage, although it could account for the very wide spacing of hedgerows preferred by farmers. The major remaining constraints are the importance of livestock, and the extensive livestock management practices. Contour hedgerows may indeed contribute to maintaining the productivity of cropped land, but by focusing on options for cropland, scientists are only addressing a small component of a much wider productivity and environmental problem which requires more complex social and managerial changes. If attitudes to the value and productivity of livestock change, more intensive management may be possible, at which stage hedgerows or other arrangements for fodder production may be an important integrated factor in farm management.

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Acknowledgements

This paper is an output from project R6638 funded through the Natural Resources Systems Programme of the UK Department for International Development (DFID) for the benefit of developing countries. The views expressed are not necessarily those of DFID. Collaborators on the project are Miguel Eid, Osvaldo Montenegro and Eduardo Sandoval; I thank them for helpful discussions.

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Participatory research on vegetative soil and water conservation practices for hillside farmers

The increasing need for protection of fragile hillsides under cultivation by small-holder farmers in developing countries has been the catalyst for a programme of participatory on-farm research and development, funded by DFID and led by SRI. Work has been conducted in Latin America in partnership with farmers, research organizations, NGOs and rural development projects. Emphasis has been on affordable and adoptable vegetative practices (contour live-barriers and leguminous cover crops). The effects of these practices on soil erosion and fertility, pest and weed incidence and crop yields has been monitored. In addition, and crucially, the economic sustainability of the practices has been assessed from the farmers' perspective. The research programme started in Mexico, Nicaragua and Honduras and is now based in Honduras and Bolivia. Results have shown that the practices are effective, accepted by farmers and lead to improved productivity on hillside farms.

Introduction

In many regions of the world small-holder farmers are obliged to eke out a precarious existence in areas of steep, erodible hillsides

The participation of farmers and intermediate users (NGOs and development projects) has meant that the projects have not only quantified technical and economic parameters of the practices studied, but have also ensured that uptake routes for them have been in place since the outset

which are ill suited to the production of annual crops with conventional tillage techniques. Frequently the farmers are not in this predicament by choice, but are driven by economic, social and political factors to produce crops from soils which would, logically, best be left to forest or permanent tree crops (Sims *et al.*, 1996a; Sims, 1996).

One of the results of this situation has been a growing emphasis amongst the development movement to promote organic farming techniques (with low or zero dependence on purchased inputs) for soil conservation and fertility enhancement. However little has hitherto been done to quantify the technical and economic consequences of adoption of the practices.

The themes presented in this paper give an overview of the approach and results of a programme of systems-based, farmer-participatory research which started in 1991 in Mexico, Nicaragua and Honduras and continues to date in Honduras and Bolivia. The research programme has had the following objectives:

- To develop farmer-adoptable soil and water conservation techniques.
- To assess the technical implications and the social and economic impacts of proposed innovations.

The adoption of successful practices would, in turn, lead to a reduction in soil erosion, an increase in water conservation and could result in a reduction in deforestation as the longevity of hillside plots is increased.

Selection and performance of the practices

In all the hillside areas selected, an initial appraisal of the farming systems was conducted using informal participatory survey techniques (Sims *et al.*, 1996b; Céspedes, 1996). Soil erosion and its associated lack of fertility, leading to the short life (two to three years) of hillside plots, was identified as a technical problem of paramount importance to the farmers. This, coupled with the chronic shortage of capital typifying the farming systems, led to the investigation of low-cost solutions. These have centred on vegetative practices and, more specifically, the use of live barriers on the contour to stabilize the slopes followed by the introduction of leguminous cover crops in the rotation to raise the fertility of the stabilized plots.

Live barriers. The species that can be used depend on several factors. First, there are the physical factors of climate, altitude and soil type. Then there are farmer preferences. One farmer in Honduras is extending his barriers of vetiver (*Vetiveria zizaniodes*) and the leguminous tree (*Gliricidia sepium*) which have built up terraces with the deposition of 50 cm of soil over five years (Figure 1). He claims multiple uses for the wood produced by the trees, including the pleasure of resting in their shade and listening to the birds that nest there. Other farmers have eschewed the trees arguing that they reduce crop production adjacent to the barriers. Yet others have opted for king grass (*Pennisetum* spp.) which provides valuable fodder for animals and cash income in the dry season even though it invades the cropping area (Figure 2). At high altitudes these species will not thrive and mixtures of phalaris (*Phalaris tuberoarundinacea*) and kishuara (*Buddleja coriacea*) are proving to be more suitable (Figure 3). Many other examples of barrier species have been tried.

Figure 1. A farmer who has adopted to maintain the Gliricidia *trees in his vetiver-*Gliricidia *contour barriers. The barriers have, in three years, accumulated 50 cm of soil above the grass and the farmer can now grow a crop of sorghum after his maize on the conserved residual moisture.*

Figure 2. Pennisetum *spp. grasses, although excellent for natural terrace formation and animal fodder, tend to invade the cropping area which may cause their rejection.*

Figure 3. A recently established barrier of Phalaris and kishuara at an altitude of 4000 m.

Cover crops. The introduction of cover crops into rotations to increase soil fertility is the next step in improving sustainability of crop production on hillsides. Legumes such as mucuna (*Mucuna pruriens*), canavalia (*Canavalia ensiformis*), lab lab (*Dolichos lablab*) and chinapopo (*Phaseolus coccineous*) have proved successful in the lower areas. The adopted practice is to relay sow them in association with the maize crop. At altitude in the Bolivian inter-Andean valleys, species such as tarhui (*Lupinus mutabilis*) and vicias (*Vicia* spp.) are being indicated as the favoured options.

Evaluation. Evaluation of the effects of the practices are continuing but early indications show them to be effective in achieving the goals of conservation of soil and water and improving crop yields and they are economically attractive to small-holder farmers (Walle and Sims, 1997; Ellis-Jones and Sims, 1995). The impact on pests is not yet clearly defined although there is evidence that maize ear rot (*Stenocarpella maydis*) is increased with the maize - legume inter-cropping system in hotter climates (Jirón, 1997). On the other hand the system markedly reduces weed competition for the main crop.

Implications and future work

The participation of farmers and intermediate users (NGOs and development projects) has meant that the projects have not only quantified technical and economic parameters of the practices studied, but have also ensured that uptake routes for them have been in place since the outset.

In the case of the Central American countries and Mexico there has been a tendency to adopt the 'organic' farming development package which emphasises the use of labour intensive hillside conservation works, the incorporation of organic manures and a bias against purchased inputs such as inorganic fertilizers and agrochemicals. Adoption of these practices has not always been as great as expected in many cases because of the unacceptably high labour demand and the limited productivity enhancement. The experience of the RNRRS research projects is that live-barriers are the most successful as far as farmer adoption is concerned and this is due to their stabilizing effect and the potential that they offer for profitable longer term investment in hillside farming. For example, if before construction of live contour barriers a hillside plot with a 50% slope would last three years from initial use before becoming so unproductive that it was abandoned, stabilization with barriers means that production can continue over a much longer period and justifies the use of fertility enhancing practices such as cover-crops and purchased fertilizers.

The relatively simple techniques developed and employed for technical and economic analysis have been distributed to other projects working in the area of hillside conservation in several Latin American countries where they can be employed to evaluate alternatives and produce best-bet options for a range of agro-ecological conditions. This need is being taken further by the development of a computer model which predicts the performance of conservation practices under different physical and management domains (Quinton, 1997).

In the case of Bolivia, the practices have been a novelty to the majority of the farmers involved and they are appreciating the extensive advantages of adoption. A complementary participatory research project coordinated by Reading University is examining how farmers adapt such practices into existing systems, when the farmers themselves are completely in control of the technology design.

The future direction of the research programme will include even greater farmer participation in the technology selection and evaluation process. It will also concentrate on increased complementarity with other research and development projects to promote integration of the products of the vegetative practices into the farming systems. Examples would be increased animal fodder production (from barriers and legume crops) in the dry season, more saleable products (seeds and fruit, for example) from the practices and shortened fallow periods (presently up to ten years). Further development of the erosion simulation model will allow extrapolation of the results over wide areas with similar agro-climatic conditions.

The combination of these factors, close integration with intermediate users and the development of practical courses for extensionists, will take the successful results of the programme to the hillside farmer by the fastest route.

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Acknowledgement

The research projects summarised were funded by the Natural Resources Systems Programme of the UK Department for International Development (DFID). The views expressed are not necessarily those of DFID. Research organizations involved in the collaborative work were: National Forestry and Agricultural Research Institute (*Instituto Nacional de Investigaciones Forestales y Agropecuarias* - INIFAP, Mexico); National Agrarian Reform Institute (*Instituto Nacional de Reforma Agraria* - INRA, Nicaragua); Ministry of Natural Resources (*Secretaría de Recursos Naturales* - SRN, Honduras); Panamerican Agricultural School (*Escuela Agrícola Panamericana* - EAP, Honduras); San Simon University (*Universidad Mayor de San Simón* -UMSS, Bolivia); Centre for Tropical Agricultural Research - *Centro de Investigación Agrícola Tropica*l - CIAT, Bolivia). The projects have also worked closely with a wide range of rural development NGOs and, of course, collaborating hillside farmers in all the countries.

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Live barriers on hillside farms: are we really addressing farmers needs?

The ability of different live barrier treatments to control soil erosion was tested at a trial site in southern Honduras. Four treatments were used: control with no live barrier; live barriers of *Vetiveria zizanioides* (vetiver grass); live barriers of *Gliricidia sepium* (Gliricidia); and a *V. zizanioides/G. sepium* mixture. After two wet seasons there were no significant differences in reduction in soil loss between the treatments. Qualitative and quantitative research demonstrated that farmers in Honduras prefer live barrier species that contribute to the farm household in terms of the production of fruit or other products in addition to retaining soil. Farmers, therefore, tend to favour different live barrier species to those traditionally promoted in soil and water (SWC) conservation programmes. Research also demonstrated that farmers seldom see SWC as a priority problem. In the absence of subsidy and in order to ensure greater farmer adoption and adaptation, live barriers should be promoted with other technologies, such as cover crops, as part of programmes whose primary objective is enhanced and sustainable agricultural production as opposed to soil and water conservation *per se.*

Introduction

The majority of the developing world is faced with the need to increase agricultural production from land already in use. One of the challenges in the tropics and subtropics is, therefore, to intensify the output from the land without destroying the soil resource upon which it all depends (Shaxson, 1993). Erosion-induced loss in soil productivity is now recognised as one of the principal threats to agricultural sustainability (Pretty, 1995) but in terms of farmer adoption, SWC projects have not always been successful. Research described in this article was conducted in two regions in Honduras (Güinope and Choluteca) on the use of live barriers on hillside farms, and was directed at three related themes:

- What live barrier species are actually favoured by farmers and are they the same species that have been promoted in SWC programmes?
- Is one of the reasons for non-adoption of live barriers (and other SWC technologies) because they are not seen by farmers as relevant *i.e.* they do not address farmers' main needs?
- What are the most effective live barriers species for controlling soil erosion and are they the same as those species favoured by farmers?

Species choice and farmers' preferences

In the 1980s, the non-governmental organisation World Neighbors promoted a number of SWC technologies in the Güinope region in southern Honduras. These included live barriers of *Pennisetum purpureum* (Napier grass) and *Pennisetum purpureum* x *Pennisetum typhoides* (King grass). A rapid rural appraisal at the end of 1995 showed that many farmers had adapted the live barriers to include other species than the two grass species originally promoted. A quantitative study was subsequently carried out to document what species farmers are using in live barriers (Table 1) and their reasons for adapting the technology. Sixty-eight farmers were randomly selected for interview in 15 communities from a list of 299 farmers who had adopted live barriers during the World Neighbors programme irrespective of whether they had rejected, continue to use or had adapted the technology since the end of the World Neighbors programme.

In terms of farmer adoption, SWC projects have not always been successful

Qualitative and quantitative work has confirmed that farmers are selecting species for use in live barriers as much for their contribution to the farm household (through consumption or sale of the products of the barriers) as for the species' ability to capture eroded soil

Farmers recognised the advantages of the two species promoted by World Neighbors in terms of controlling soil erosion but they cited three major problems:

- Both species are invasive if not regularly managed.
- Although both species provide excellent fodder, few farmers in Güinope have cattle and therefore there is little demand for the amount of fodder produced.
- The species have an extensive root system and compete with agricultural crops for water and nutrients.

Qualitative and quantitative work has confirmed that farmers are selecting species for use in live barriers as much for their contribution to the farm household (through consumption or sale of the products of the barriers) as for the species' ability to capture eroded soil. Farmers are aware that their preferred species are less effective than *P. purpureum* and *P. purpureum* x *P. typhoides* in controlling soil erosion but from their point of view they are more efficient because they confer other benefits in the short-term. This concurs with research in the Philippines (Fujisaka, 1993) and in Sri Lanka where there is interest in cinnamon in live barriers as opposed to *G. sepium* even though the latter grows faster and is more effective as a hedgerow species (Sinclair, 1995).

Farmers' preferences in Güinope are often perfectly rational. Farmers with live barriers of tall species, such as fruit trees and *S. officinarum* (sugar cane), tend to be those growing *Zea mays* (maize) and *Phaseolus* spp. (beans). Competition from the live barrier species and the subsequent reduction in agricultural production in one or two lines above and below the barrier, is compensated for by the productivity of the barrier itself. Where higher-value vegetables are grown in Güinope, the reduction in crop yield is not compensated for by the value of products of the live barriers and farmers prefer shorter species such as *A. comosus* (pineapple) and S. *geniculata* (rice grass).

Do live barriers really address farmers' needs?

If live barriers and other SWC technologies are to contribute to more sustainable agriculture and rural development, they have to be popular with farmers. A first step is to find out more about farmers' concepts of soil and land. Are they the same as ours? What are the issues that farmers are concerned with: is soil erosion actually perceived as a problem? Is the poor uptake of SWC technologies partly because farmers do not see recommendations as appropriate to their problems or needs?

A qualitative study on the above themes was carried out with 30 farmers in both Güinope and Choluteca. A number of investigative tools were used including focus group meetings, semi-structured interviews, workshops and the use of concept maps. Results confirmed the following:

- Farmers are managing a complex world of natural resources, human values and economics in which SWC is but one small component.

Table 1. Most common live barrier species used by farmers in the Güinope region.

Scientific name	Common name	Products of the species
Grass species		
Vetiveria zizanioides	Vetiver grass	Roots [have medicinal properties]
Cymbopogon citratus	Lemon grass	Leaves [used in tea]
Pennisetum purpureum	Napier grass	Leaves [used for animal fodder]
Pennisetum purpureum x Pennisetum typhoides	King grass	Leaves [used for animal fodder]
Setaria geniculata	Rice grass	
Panicum maximum	Guinea grass	
Saccharum officinarum	Sugar cane	Juice and raw sugar
Trees, shrubs and other plants		
Cajanus cajan	Pigeon pea	Peas [for consumption]
Manihot esculenta	Cassava	Edible crop
Coffea arabica	Coffee	Fruits
Citrus limetta	Lime tree	Fruits
Citrus sinensis	Orange tree	Fruits
Prunus persica	Peach tree	Fruits
Gliricidia sepium	Gliricidia	Firewood
Musa acuminata	Plantain	Fruits
Ananas comosus	Pineapple	Fruits

- Neither the control of soil erosion through the use of live barriers nor SWC in general are priorities for farmers. Farmers mentioned a plethora of more urgent problems such as lack of land security and the need for rural credit.
- Farmers stressed that often these more urgent problems need to be resolved before they are willing to adopt SWC technologies such as live barriers. Several farmers who rent land pointed out that if they were to adopt SWC technologies such as live barriers and 'improve' the land, the owners would take it back earlier than would otherwise have been the case.

Live barrier trial site

In April 1996 a trial to test different species' ability to control erosion was established in southern Honduras at 87^0 04′ W and 13^0 17′ N. The wet season, which is bimodal, lasts from May until October. These six months account for approximately 90% of the annual precipitation which exceeds 2000 mm.

Research plots measure 24 x 5 m, the live barriers are at 6.0 m intervals and all plots are planted with maize. The trial is a split plot design. The main plot treatment is slope and there are two slopes (35-45% and 65-75%). The sub-plot treatment is the type of barrier used. There are four sub-plot treatments: i) control with no live barriers ii) barriers of *Vetiveria zizanioides* (vetiver grass) iii) barriers of *Gliricidia sepium* (Gliricidia) and iv) barriers of *V. zizanioides / G. sepium.* Sub-plot treatments are replicated as follows:

1. Four sub-plot treatments replicated twice on each slope angle with the runoff collected in plastic-lined catchpits. Total 16 plots. Total amount of sediment loss is calculated at the end of the wet season.
2. Two sub-plot treatments (control and *V. zizanioides/G. sepium* barriers) replicated twice on each slope angle with the runoff collected in barrels. Total eight plots. Total amount of sediment loss is measured after each runoff event.

Figure 1 shows total soil loss (kg) and water loss (litres) for 1996 and 1997 from the eight plots where runoff is collected in barrels after each runoff event. In 1996 there was considerable variation across the site with total soil loss varying from 125.2 kg (10.4 t ha^{-1}) in the case of one of the steep slope plots planted with live barriers of *G. sepium* and *V. zizanioides.* Water loss varied from 11 200 to 16 700 litres (935 000 to 1 394 00 litres ha^{-1}) in the case of the two steep slope control plots. Soil loss recorded by the catchpits for the four sub-plot treatments was within the same range as that recorded by the barrels.

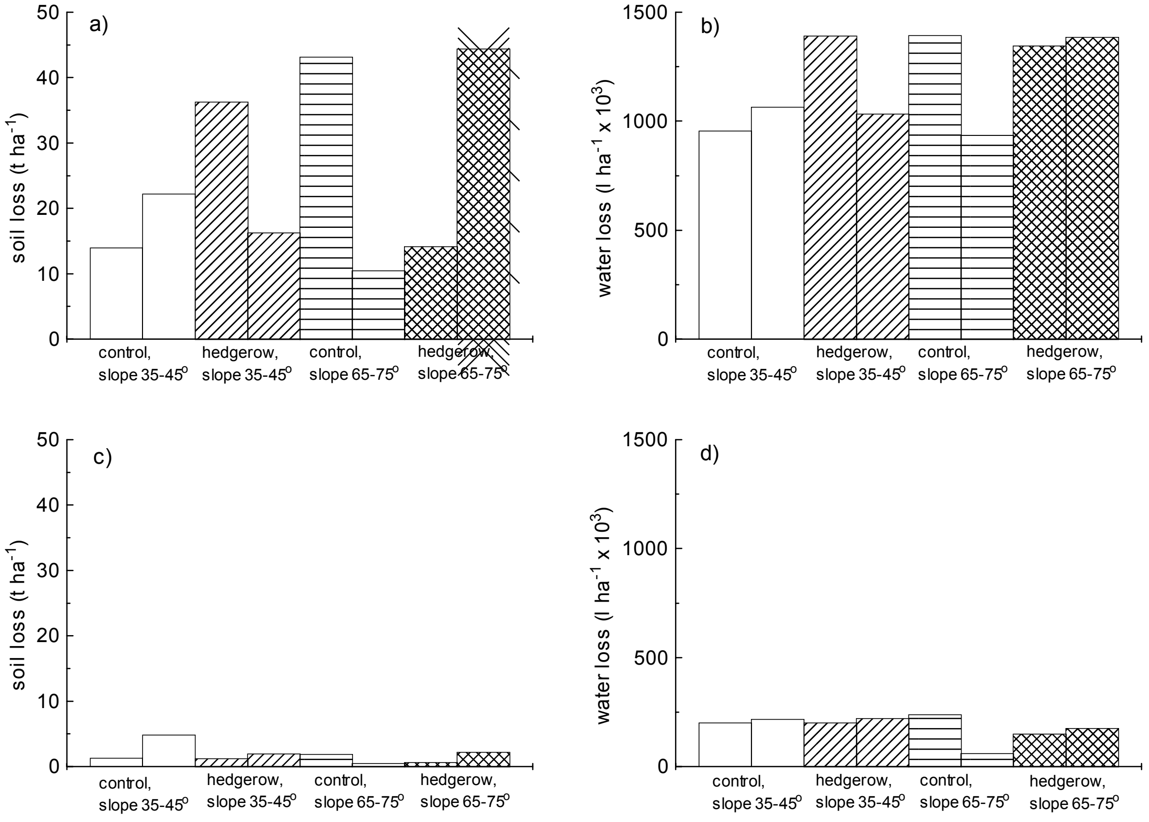

Figure 1. Annual soil and water loss a) soil loss 1996, b) water loss 1996, c) soil loss 1997 and d) water loss 1997.

A farmer's priority is often increased and sustained agricultural production and not the control of soil erosion or soil and water conservation *per se*

An analysis of variance of soil loss (24 plots) and water loss (eight plots) in 1996 showed that slope at the main plot stratum and barrier effect at the sub-plots stratum were not significant, nor was the interaction between the two.

The live barriers were established at the end of July 1996 and had not fully developed by the end of the wet season. End of season sediment losses were therefore used as covariates in the analysis of results from 1997. The effects of *El Niño* meant that there was less rain and fewer intense rainfall events in 1997 than in 1996. Several single rainfall events in 1996 generated more soil and water loss than the cumulative losses for the entire 1997 rainy season. In 1997 soil losses ranged from 5.7 kg (0.5 t ha^{-1}) in the case of one of the steep slope control plots to 58.1 kg (4.8 t ha^{-1}) in a shallow slope control plot (soil accumulation in catchpits will be collected at the end of the rains). Water loss varied from 723 to 2866 litres (60 000 to 239 000 litres ha^{-1}) in the case of the two steep slope control plots. An analysis of variance of soil loss (eight plots) and water loss (eight plots) again showed no significant differences at the main plot or sub-plot strata.

Conclusions

- Rural people ultimately decide how their land will be managed and recommendations for change must be perceived to be beneficial, often in the short-term, by the supposed beneficiaries. Many of the live barrier species promoted by development programmes seldom give short-term economic returns. In addition there may not be significant differences, in the short-term, in different species' ability to control soil erosion. This raises the question why emphasis continues to be directed at species such as *V. zizanioides* when farmers are more interested in species such as *A. comosus* (pineapple), and *S. officinarum* (sugar cane) which can give short-term benefits, and fruit trees.
- There is a danger that soil conservation is elevated to the primary research need in agricultural development programmes and productivity is often seen as a by-product. A farmer's priority is often increased and sustained agricultural production and not the control of soil erosion or SWC *per se*. In this context live barriers can end up complementing a farming system in ways that researchers and development workers have not envisaged; for example some farmers in Choluteca have established live barriers because it helps them sow maize at a more regular spacing in the inter-barrier areas, which in turn means higher yields. They do not mention the use of the barrier to control soil erosion.
- Live barriers ought to be promoted as part of a more holistic development effort where the emphasis is on agricultural production (through more conservation-effective farming practices) and human development rather than SWC *per se*. Live barriers alone are unlikely to maintain or improve soil fertility except in the area immediately above the barrier and hence an alternative approach is to promote live barriers in combination with other technologies, such as cover crops, that are able to maintain or improve all aspects of soil quality and decrease its erodibility (Shaxson *et al*., 1997).
- There needs to be greater recognition that many of the obstacles to farmers' adopting SWC technologies such as live barriers are social and political in nature and include lack of secure access to land. Until some of these constraints are lifted or subsidies offered, farmers may be reluctant to adopt any SWC technologies or conservation-effective farming practices.

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Acknowledgements

This paper is an output from project R6292 funded through the UK Department for International Development (DFID). The views expressed are not necessarily those of DFID. The authors are grateful to Andrew Pinney (DFID) for advice on the statistical analysis.

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M.A. McDonald, P.A. Stevens, J.R. Healey and P.V. Devi Prasad

Maintenance of soil fertility on steeplands in the Blue Mountains of Jamaica: the role of contour hedgerows

An experiment was established in the Blue Mountains of Jamaica to investigate the consequences of secondary forest clearance for agriculture, and the effectiveness of the contour hedgerow system in controlling soil erosion and maintaining soil fertility on steep slopes. Surface water runoff, soil erosion, rainfall interception and soil conditions were recorded following forest clearance. The results show that considerable protection is offered to both the soil and water resource by the forest, even though it is of a secondary nature. In particular, the forest acts as a buffer against fluctuations in runoff associated with rainfall events, which is of significance in large-scale events, which cause considerable erosion. Agricultural use of cleared land does result in increased erosion, and the incorporation of hedgerows of *Calliandra calothyrsus* reduced runoff and erosion compared to the conventionally farmed plots. The presence of the hedgerows had a positive effect on crop production.

Introduction

The context for this study is the urgent need to find a stable and sustainable alternative to shifting cultivation on steeplands in the tropics. In Jamaica, as in other mountainous regions, it has been accepted that cultivation will continue on many areas of sloping land, and ways must be found to make this environmentally acceptable. Sloping lands are an identifiable type of environment with a distinctive set of problems (Young, 1989). Thus, if it is a basic tenet that the control of soil erosion is only one aspect of soil conservation, then in practical development planning, it should not be treated in isolation, but integrated with maintenance of soil fertility, water availability and other aspects of agricultural improvement. Suitable measures must provide small-holder farmers with the means to sustain crop yields and reduce labour inputs to shifting cultivation.

Contour hedgerow intercropping is a simple technique which has the potential to exist on fairly meagre resources, and to build gradually upon local initiatives, while depending on local knowledge, technology and labour. The technique involves the growing of hedgerows of trees, or a perennial crop, as a barrier along the contours of a slope, with the areas between the hedges being used for agricultural production. Most hedgerows have been established with a single species, the desirable characteristics of which include a supply of viable seed, vigour, fast growth, nitrogen fixation, copious biomass for the production of mulch, manure, fodder, fuelwood and other useful by-products. On steep slopes, one of the principal reasons for hedgerows is erosion control; and in those places the by-products might be of secondary importance, except to the farmer (Pellek, 1992).

Objective

The principal objective of this study was to investigate the consequences of forest clearance by shifting cultivators on consequent soil fertility. The use of a potential agroforestry system - contour hedgerows - for soil conservation was also investigated as a means to provide a stable and sustainable agricultural production system for sloping lands in the tropics.

Methods

An experiment was undertaken with the participation of local farmers in the watershed of the Green River, a head-water tributary of the Yallahs River which is the main supplier of domestic water to the municipality of Kingston, Jamaica. The elevation is around 1 500 m and annual rainfall is, on average, 2 500 mm.

Experimental plots were established in:

1. Secondary forest
2. Forest cleared, burned and subsequently maintained weed-free
3. Forest cleared, burned and planted with agricultural crops
4. Forest cleared, burned and planted with agricultural crops intercropped with *Calliandra calothyrsus* hedgerows - a ubiquitous, locally popular species.

Four blocks each containing one plot of each treatment were established in the Green River Valley in areas of secondary forest, between 20-30° slope, originally cleared for coffee, cinchona or agriculture and subsequently abandoned. Each plot is 10 m x 20 m, with an inner assessment plot 8 m x 15 m. The plots were cleared in July 1992 in accordance with local practice - smaller trees were removed with cutlasses, and the larger ones with axes. The plots were subsequently left to dry until August and then broadcast burned. The plots were left for up to three weeks to 'sterilise the soil' (local practice)

Individual storms accounted for large proportions of total runoff

In the agroforestry plots, erosion was up to 30% less than for the conventionally farmed plots in the first year after clearance

and planting of trees and crops began in September 1992. Escallion, thyme, maize, carrots, Irish potatoes, beetroot, cabbage, sweet pepper and cucumber are amongst the major crops cultivated in the area for subsistence and sale in the local markets, and a mixture of these crops has been established in the agricultural plots. The hedging system was designed after Young (1989) and involves three hedgerows per plot. The hedgerows are 5 m apart and comprise triple rows of trees at 1 m intra-row spacing and 0.5 m inter-row spacing. The trees were grown from locally collected seed. The hedges have been cut bi-annually since planting to a height of about 30 cm, and were never allowed to grow more than about 1 m tall, at which point they started to shade the crops. Initially, the prunings were used to fortify the hedges, but subsequently, they were chopped up and used as mulch on the farmed area between the hedges. Biomass production was recorded at each cut. Each block of plots was farmed and managed by a local farmer.

Three Gerlach troughs were installed in each plot (Morgan, 1979), each of 1 m length. Samples of runoff and sediment were collected on a fortnightly basis from September 1992 to September 1995, and after every rain event >25 mm from March 1996 to present. Total mass of sediment eroded was recorded, and the entire sample separated into particulate organic matter, coarse (>2 mm) and fine (<2 mm) mineral fractions. A bulked sample of the sediments collected from each plot over each year was compiled and analysed for exchangeable base cations - Na, K, Ca, Mg and total N, P and C.

Three soil cores were collected from each plot, prior to clearance in June 1992, and analysed for bulk density, pH, N, P, C, exchangeable Na, K, Ca, Mg, and particle size analysis. The soil sampling and analyses were repeated in October from 1993 - 1996. Additional samples were collected from the agroforestry plots post-clearance - in addition to the areas between the hedgerows, samples were collected from under the hedgerows. A limited range of these data are presented here.

In-situ incubations (30 day) were conducted in the plots in October from 1994-1997 to assess rates of total nitrogen mineralisation and nitrification.

In 1996, line planting of *Zea mays* was conducted to evaluate any effect of the hedgerows on crop productivity. The plants were established at 50 cm spacing, both between plants and between rows. Lines were established at the same spacing in the agriculture plot. At harvest, measurements were taken of plant height, above-ground biomass, cob length, cob weight and % cob grain fill. Only data for grain production are presented here.

Results

Levels of runoff over the course of each year were very low in all plots (Figure 1). Individual storms accounted for large proportions of total runoff (unpublished data). Consequently, measurements of associated erosion were much lower than previously published estimates (e.g. McGregor, 1988). However, forest clearance followed by cultivation resulted in a 31-fold increase in the quantity of eroded sediments (Figure 2). In the agroforestry plots, erosion was up to 30% less than for the conventionally farmed plots in the first year after clearance. Rates of erosion increased significantly over time in the bare treatment plots, whilst they dropped significantly in the agriculture and agroforestry plots, and showed little change in the forest plots.

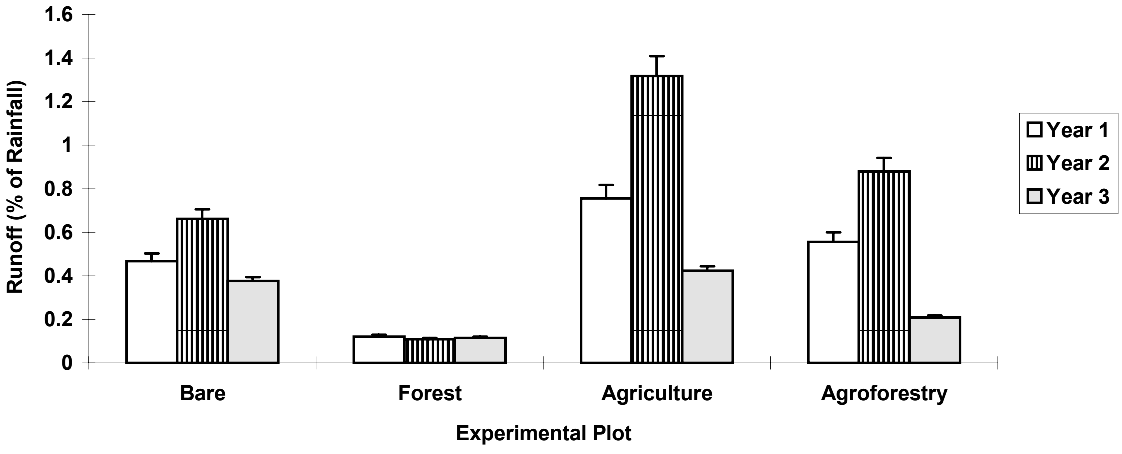

Figure 1. Runoff from the experimental plots, expressed as a proportion of annual rainfall.

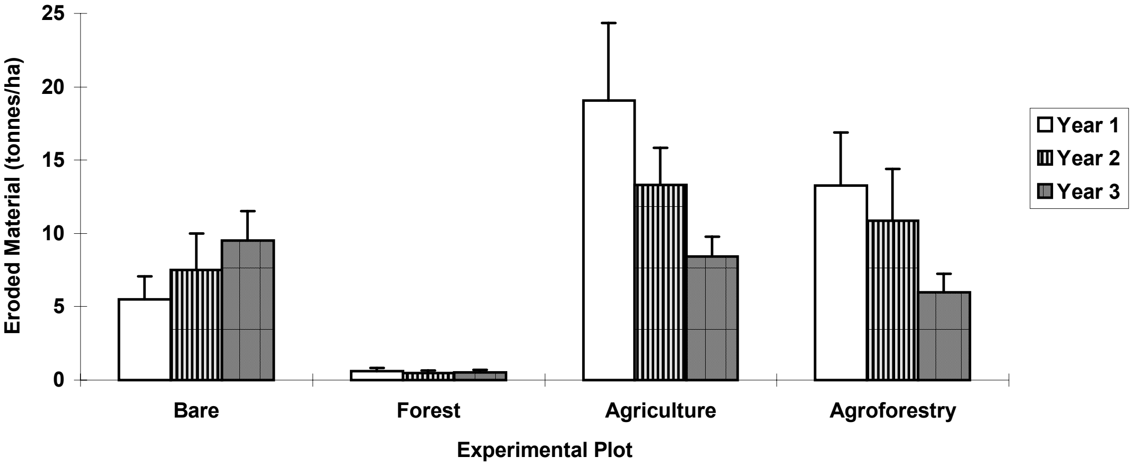

Figure 2. Sediments eroded from the experimental plots.

This pattern was mirrored in the rates of loss of mineral nutrients (Table 1). Even after the first year post-clearance, the nutrient capital continued to be depleted, though at a decreasing rate. The losses, as a proportion of the total capital, did decrease markedly year after year in the agriculture and agroforestry plots, but not in the bare plots. In the agroforestry plots, these losses should have been more than offset by the productivity of the hedgerows (Table 2). However, although there was an increase in the rate of nitrogen mineralisation rate below the hedgerows (Figure 3), there was net immobilisation in the farmed areas between the hedges. This was probably as a result of the prunings being scattered on the soil surface. The effect was more marked in later years as a greater proportion of the prunings were returned to the soil, rather than being stacked behind the hedgerow to maximise the barrier effect. Nevertheless, there was a significant productivity increase in the yield of maize in the agroforestry plots compared with the agriculture plots (Figure 4). There was no difference in yields per hectare between the agriculture and agroforestry plots (unpublished data), as, obviously, there were fewer crop plants as a result of the hedgerow presence.

Table 1. Nutrient losses in sediments eroded from the experimental plots.

Year 1	Bare	Forest	Agri-culture	Agro-forestry
Soil loss (kg ha^{-1})	5476	608	19069	13279
Soil loss (mm)	0.7	0.1	2.5	1.6
N loss (kg ha^{-1})	10.4	0.3	28.9	18.5
% of capital	1.9	0.1	8.0	3.7
P loss (kg ha^{-1})	1.7	1.1	6.9	3.6
% of capital	1.5	0.0	8.2	3.7
K loss (kg ha^{-1})	0.7	0.0	2.4	1.4
% of capital	3.0	0.1	18.0	7.2
Year 2	**Bare**	**Forest**	**Agri-culture**	**Agro-forestry**
Soil loss (kg ha^{-1})	7506	474	13317	10869
Soil loss (mm)	0.8	0.1	1.4	1.1
N loss (kg ha^{-1})	9.3	0.1	14.4	13.3
% of capital	2.2	0	3.0	3.0
P loss (kg ha^{-1})	1.9	0	3.6	3.3
% of capital	1.9	0	3.3	3.3
K loss (kg ha^{-1})	0.1	0	0.1	0.1
% of capital	2.9	0	4.4	4.9
Year 3	**Bare**	**Forest**	**Agri-culture**	**Agro-forestry**
Soil loss (kg ha^{-1})	9528	532	8438	5986
Soil loss (mm)	1.0	0.1	0.9	0.6
N loss (kg ha^{-1})	7.7	0.1	7.8	6.9
% of capital	1.5	0	2.1	1.6
P loss (kg ha^{-1})	2.2	0	2.4	1.6
% of capital	1.5	0	2.1	1.5
K loss (kg ha^{-1})	0.4	0	0.4	0.5
% of capital	2.3	0	2.6	3.0

Discussion and conclusions

It would seem that considerable protection is offered to both the soil and water resource by the forest, even though it is of a secondary nature. In particular, the forest acts as a buffer against fluctuations in runoff associated with rainfall events, which may be of significance in large-scale events. Agricultural use of cleared land does result in increased erosion, but not as much as anticipated from previous estimates, and the use of contour hedgerows reduces erosive losses to levels which may be considered acceptable (Morgan, 1986). However, nutrient losses indicate the low sustainability of conventional agriculture, which brings about a significant reduction in nitrogen, phosphorus, organic matter and base cations.

The barrier hedgerow system obviously has potential for sloping lands such as encountered in this study, but its adoption by farmers depends on the simplification of its establishment and its development into a flexible system (Njoroge and Rao, 1995).

Table 2. Productivity of Calliandra calothyrsus *hedgerows (SE in parentheses).*

Total biomass produced (g dry weight tree^{-1})	1035.28 (40.63)
Total biomass produced (kg ha^{-1})	4657.50 (182.78)
Nitrogen content of foliage (%)	4.20 (0.08)
Phosphorus content of foliage (%)	0.24 (0.03)
Total nitrogen production (kg ha^{-1})	195.67 (3.90)
Total phosphorus production (kg ha^{-1})	11.00 (1.49)

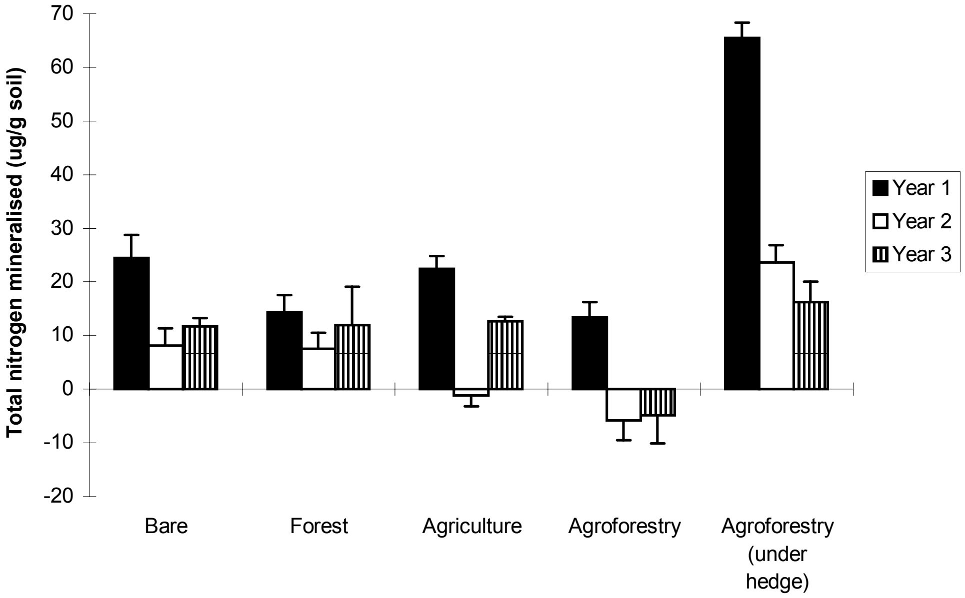

Figure 3. Total amounts of nitrogen mineralised in the experimental plots (30 day in-situ incubation)

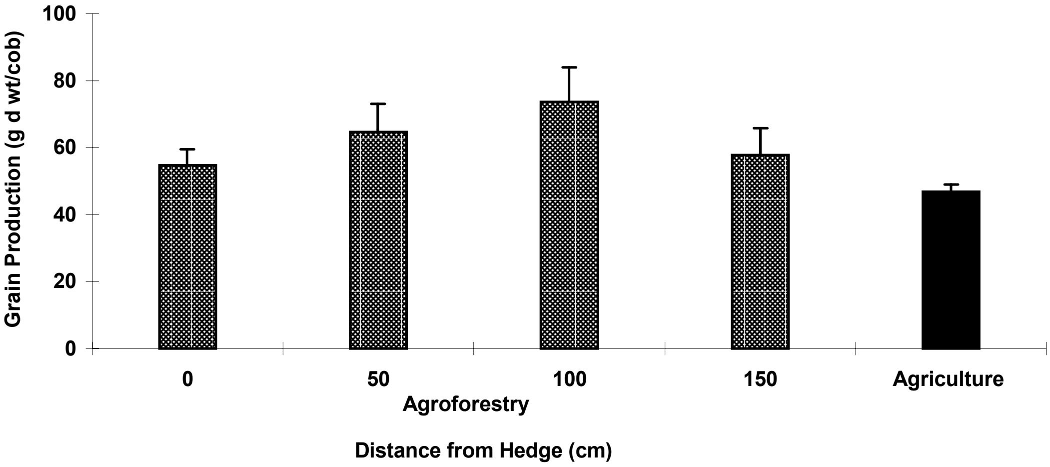

Figure 4. Productivity of Zea mays *grown in the agroforestry and agriculture plots*

Experiences of farmer adoption of contour hedgerow intercropping in Indonesia demonstrate that the system is not an 'off the shelf' technique, but rather one of a prototype, whose success was dependent on the farmer's ability to adapt the practice to their specific farming conditions (Wiersum, 1994). The technologies must be flexible enough for farmers to make modifications so that they meet their short-term economic needs (Fujisaka, 1989). This has been observed in the project area, where hedgerows of nitrogen-fixing trees are popular, but they are usually intermixed with hedgerows of species giving a direct economic return, such as Christmas or fruit trees.

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Acknowledgments

This paper is an output from project R6290 funded through the Forestry Research Programme of the UK Department for International Development (DFID) for the benefit of developing countries. The views expressed are not necessarily those of DFID.

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Soil erosion in the Middle Mountains of Nepal

The Himalayan Degradation Hypothesis suggests that increased conversion of forest to agricultural land in the Middle Mountains of Nepal has led to accelerated soil erosion and decline in soil fertility. However, assessment of the scale of the problem is complicated by differences in the land use systems studied and the methodologies used. Soil loss under agriculture is primarily dependent on the unpredictable pre-monsoon rains - once the vegetation has recovered from early season ploughing, further soil losses are low. Recent studies which have used the same methods to compare erosion in contrasting land use systems over the same time periods have indicated that the levels of soil loss are much less under cultivation than previously suggested, but are highly variable and can be unsustainable.

Context

The Middle Mountains of Nepal are home to approximately half the population of this small mountain kingdom occupying the politically sensitive area between India to the south and China to the north and east. The great majority of the expanding population in the mountain zone are dependent upon subsistence agriculture for their livelihoods, and there has been considerable debate over the past 20 years as to the effects of land use change, primarily invoked by population growth, on soil erosion in this geomorphologically fragile environment.

The debate has centred around the 'Himalayan Degradation Hypothesis' originally put forward in the early 1980s, in which rapid and recent deforestation to provide more agricultural land to meet the needs of the increasing population was hypothesized to have profoundly negative environmental effects. These included increased runoff and propensity to flood downstream on the plains of India and Bangladesh, siltation of reservoirs and accelerated soil erosion and soil fertility decline in the hills themselves. However, it was not until the mid 1980s that rigorous field data started to become available with which to test this hypothesis. One of the first indications that the hypothesis was oversimplified came from extensive analysis from aerial photography of the rates of deforestation (LRMP, 1986) which showed that within the Middle Mountains zone forest cover actually increased by 1.8% between 1964 and 1979. This finding was consistent with research by Mahat *et al.* (1986) which suggested that deforestation had been a gradual process over several hundred years and culminated in relatively high levels of conversion to cultivated land in the 1940s and 1950s during a period of political uncertainty and when this was promoted by tax concessions, and not in the more recent period of population increase.

While issues of deforestation and land degradation have undoubtedly been oversimplified, there can be no doubt that there is accelerated soil erosion on some cultivated lands

Similarly, the issue of highland/lowland interactions, that is land use change in the Himalaya affecting hydrological regimes on the plains and the delta areas, has been shown to be more complex and remains little understood owing to the different temporal

The estimates of erosion losses on rainfed cultivated land recorded differ by two orders of magnitude

In the years monitored over 40% of the monsoon loss occurred in a small number of pre-monsoon storms, when the ground was freshly ploughed and crop and weed cover was low

Traditional soil conservation measures inherent in the different farming systems do vary, providing scope for the transfer of indigenous knowledge between regions

and spatial scales involved and the paucity of relevant measurements. However, it is increasingly believed that flooding on the plains owes much to regional meteorological conditions in the lowland area and has only a tenuous link to land use change within the mountains.

Soil erosion data

Whilst issues of deforestation and land degradation have undoubtedly been oversimplified there can be no doubt that there is accelerated soil erosion on some cultivated lands. The number of studies with which to evaluate this are small, and the interpretation of them is often severely hampered by their use of different field methodologies, frequency of measurement, location of study areas, farming systems under study, duration and timing of studies, sophistication of the analyses and availability of rainfall intensity data. The majority of such studies have used erosion plots but of widely differing sizes and designs; and some have used Universal Soil Loss Equation estimations in a system where no calibration for USLE exists. It is perhaps hardly surprising therefore that the estimates of erosion losses on rainfed cultivated land recorded in the various studies differ by two orders of magnitude from less than 1 t ha^{-1} yr^{-1} to an estimated 200+ t ha^{-1} yr^{-1} (Carson, 1992). When the purely quantitative studies at the hillslope and field scales are considered the range of estimated losses is still substantial, extending from less than 1 t ha^{-1} yr^{-1} to over 100 t ha^{-1} yr^{-1}, as shown in Table 1. This reflects levels of loss that would be tolerable in such environments to those that are clearly unsustainable. Unfortunately, in these past studies it remains impossible to assess the extent to which the differences in recorded soil losses are a reflection of real differences between areas and farming systems, or the artefact of the different field methodologies.

There are two main reported studies which have measured erosion on different land uses within the same area using plot-based studies, over the same time scales and using internally consistent methodologies. These facilitate some evaluation of the role of land use change in causing accelerated soil losses at the field scale.

Table 1. Soil loss estimates from agricultural land in the Nepal Middle Hills.

Location	Management	Soil loss (t ha^{-1} yr^{-1})	Reference
Fakot	Terracing - improved	1.3 - 4.4	Anonymous, 1984
	+ mulch	0.2	
	Terracing - poor	2.8 - 4.9	
	Natural grass	2.1	
Chisipani	Conventional tillage	0.6	Maskey and Joshi, 1991
	+ fertilisers	1.2	
	Minimum tillage	0.2	
	+ cover crop	0.3	
Chyandanda	Conventional tillage	14.0	Maskey and Joshi, 1991
	Alley crop - hedge	105.0	
	Alley crop - bananas	54.0	
	Hillside ditch	94.0	
	Strip cropping	2.1	
Kulekhani	Traditional cultivation	1.5	Upadhaya, Sthapit and Shrestha, 1991
	+ contour ridging	2.2	
	Traditional cultivation	1.4	
	Hillside ditching	2.1	
Bhandar	Traditional cultivation	0.0	Ries, 1994
	Traditional cultivation	1.0	
Bamti	Traditional cultivation	3.0	Ries, 1994
Pakhribas	Cultivated fallow	25.0	Sherchan, Gurung and Chand, 1991
	Maize/millet traditional	35.0	
	Maize/millet improved	24.0	
	One crop maize	30.0	
	+ min tillage/mulch	18.0	
Jikhu Khola	Traditional cultivation	0.1 - 38.0 (1992) 0.2 - 37.0 (1993) 2.6 - 42.0 (1994)	Carver and Nakarmi, 1995
Likhu Khola	Maize/millet traditional	1.0 - 13.0 (1992) 2.8 - 8.2 (1993)	Gardner and Gerard, 1995

Figure 1a. Temporal pattern of monitored event rainfall in relation to runoff.

Figure 1b, c. Temporal pattern of change in soil loss in relation to vegetation cover in two plots.

Ries (1994) examined erosion on ten test plots in 1990 and 1991 in the High Mountain region of the Eastern Central Himalaya around Bamti, Bhandar and Surma. Plots were 14 and 28 m^2 and daily measurements were taken. Erosion levels were relatively low at 9 t ha^{-1} yr^{-1} for maize and maize/millet relayed cultivation, with runoff at 11% and less. The highest erosion rates were recorded in the extensively used field-pasture shifting cultivation (bukma system) in the cropping year under potato cultivation. Suspended sediment delivery in the surrounding small subcatchments, the

Until uniform procedures are in place there is little point in attempting meaningful inter-study comparisons

largest of which was 5.7 km^2, ranged between 2.08 and 29.85 t ha^{-1} yr^{-1} monsoon, and were thus a similar order of magnitude to the test plots. In contrast, the larger catchments in east Nepal are characterised by suspended sediment delivery rates of between 13.2 and 80 t ha^{-1} yr^{-1} monsoon, raising the question of the source of the sediments in the larger systems.

The second study (Gardner and Gerard, 1995) was located in the Likhu catchment of the Middle Mountains immediately to the north of the Kathmandu Valley. A total of 29 erosion plots were instrumented and most were monitored for three years between 1992 and 1994. In general, between 35% and 50% of individual storms were monitored, including the majority of the high magnitude events. Plot size was variable as plots were designed to follow the local topography of the steep land and of the agricultural terraces so as to interfere as little as possible with the 'natural' drainage patterns. However, the downslope distance of the plots was kept as similar as possible and was generally between 3 and 7 m. Runoff and erosion was greatest in the highly degraded forest areas and along well used pathways, with erosion reaching over 35 t ha^{-1} yr^{-1} in 1992 and 1993 (Figure 1b, c). On cultivated land erosion losses were relatively small at levels estimated between 4 and 13 t ha^{-1} yr^{-1}; during monitored events the higher losses were found on the finer textured soils. Moreover, there was a strong seasonal component to the losses in that in the years monitored over 40% of the monsoon loss occurred in a small number of heavy pre-monsoon storms in May, when the ground was freshly ploughed and the crop and weed cover was low. Lowest soil losses were recorded on grassland and secondary forest with good ground cover; in both cases these were less than 1 t ha^{-1} yr^{-1}. Such low levels are consistent with results from other studies.

Discussion

Taking the data available at face value, the conversion of forest to agricultural land would, not surprisingly, seem to result in substantial increases in topsoil loss. Subsequent abandonment of terraces to grazing land would appear to lead to a substantial reduction in losses once the grass cover was well established and providing it remained so. However, the absolute level of topsoil loss recorded is far less in both the studies reported above than previously suggested from observational (Carson, 1992) and USLE calculations (e.g. in the Phewa Watershed; Impat, 1979). Indeed, the reported levels could be considered as tolerable for such a dynamic geo-morphological system (Morgan, 1986). In the case of the Likhu the low levels owe much to weed cover protecting the ground during the peak monsoon rains, to the intricate bench terraces, and to the ditches dug at the base of each terrace riser which trap soil most effectively.

However, despite the shortcomings in the data, it is likely that there are real differences in soil losses under different farming systems and in different agro-ecological zones. In addition, traditional soil conservation measures inherent in the different farming systems do vary, providing scope for the transfer of indigenous knowledge between regions. For example, in much of western Nepal the riser ditches noted above as being of substantial benefit, are not used owing to the perceived problem of draining water onto an adjacent farmer's fields; in Palpa in the Tansen District cultural practices dictate that terraces are long (up to 30 m) and steep (in excess of 25° in places) rather than the more normal flat bench type and severe soil depletion is obvious on the steep upper parts of many such terraces. Rainfall totals are also sufficiently variable to cause large differences in losses from the same site each year, and unfortunately little data are available on rainfall erosivity and its seasonal pattern, which likewise will probably be highly spatially variable given the differences in rainfall totals.

To compare, for the first time, spatial variations in soil and nutrient loss on rainfed agricultural terraces (bariland) in different farming systems and agro-ecological zones and some of the implications of this for soil conservation, a detailed study is underway in seven areas of the Middle Mountains in western central Nepal using a standardized methodology. The study also considers the consequences of erosion for soil fertility by measuring nutrient loss from terraces via pathways related to the processes of accelerated erosion. Specifically, precise data for soil loss from controlled plots is being complemented with that for nutrients a) lost through adsorption to eroded surface soil particles, b) being leached through the soil column and c) dissolved in surface runoff. For the first time in Nepal, these data are being augmented by ^{137}Cs measurements of relative soil gains and losses on whole hillslopes. The latter is in recognition of the inadequacy of plot studies to examine cascades of soil movement and potential for eroded soil storage on long hillslopes with complex natural and human morphologies.

However, the overriding difficulty with all studies in Nepal is the variability in monsoon rainfall from year to year and spatially within the Hills which, combined with there being few erosivity measurements, prevent full analysis of the issue. If the pre-monsoon period is fundamental, as has so far been seen, then it is no more than a few hours within this period that really matter. These are the times at which rainfall intensities are above critical thresholds and the scale of losses for the whole season is likely to be determined. An example is given in Figure 1, which shows that in the Likhu Khola, whilst rainfall and runoff magnitudes of the heavier storms remain broadly constant throughout the season, soil loss clearly diminishes to inconsequential levels once vegetation cover recovers from the early season ploughing, apart from when there is further disturbance during harvesting. As the pre-monsoon storms are relatively small scale convective thunderstorms there is an element of randomness each year as to which areas, if any, suffer the severe losses associated with particularly high magnitude events, albeit that some areas have greater propensity for such storms. Similarly, even though the monsoon proper is not seen as being so important, a particularly heavy monsoon (the twenty year event?) may break through thresholds and result in severe losses. This will in all probability be missed by studies conforming to the normal project life-cycle of three years or so.

From the foregoing data and commentary, it is clear that some studies at least have revealed that soil erosion on rainfed cultivated terraces is less than hitherto predicted. Together with the evidence of relatively low rates of deforestation, it suggests that the Himalayan Degradation Hypothesis is certainly not universally applicable to the Middle Mountains of Nepal. Nevertheless, some instances of accelerated erosion have certainly been recorded, especially on the finer textured soils and on the more steeply sloping terraces. Annual variation in measured losses would be expected to be high and losses would appear to be primarily dependent on the capricious character and timing of the pre-monsoon rains in relation to land management practices. This is compounded with the absence of an agreed systematic procedure for erosion monitoring at the field scale - this is urgently required. From the available studies there would also appear to be variable evidence as to the success of introduced conservation techniques in reducing soil losses (see Table 1). Until uniform procedures are in place there is little point in attempting meaningful inter-study comparisons; and even when they are in place we forget at our peril the complexities of spatial linkages and transfers across and down whole hillslopes.

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T.R. Wheeler, J.D.H. Keatinge, R.H. Ellis, Aiming Qi and R.J. Summerfield

Selecting legume cover crops to counter soil erosion and losses in soil fertility in hillside farming systems

Legume cover crops may provide a low-cost technology to counter the risk of soil erosion and the loss of soil fertility on hillsides in the sub-tropics and tropics. A method for determining whether possible legume cover crop species are potentially adapted to a particular hillside environment is described. Models that describe the effects of temperature and photoperiod on the rate of cover crop development are utilised in order to identify potential legume cover crop species that may be recommended for further trials on local hillsides.

Introduction

Population growth in the mountainous regions of developing countries poses an increasing demand on the cultivation of hillside lands. Farming practices dominated by the production of subsistence cereal crops without adequate replacement of soil nutrients through inputs of manure, compost or inorganic fertiliser can soon render hillside farming systems unsustainable. Soil losses and reduction in inherent soil fertility are, therefore, increasingly severe constraints to crop production on steeply sloping hillsides in the tropics and sub-tropics (Gardner and Jenkins, 1995; Ellis-Jones and Sims, 1995).

A cover crop protects the soil and its fertility from erosion and benefits subsequent food crops

Communities forced to grow annual crops on steep slopes are frequently constrained by their access to economic and infrastructural resources. Their ability to provide inputs for topsoil and soil fertility maintenance is strictly limited. In these circumstances the introduction of, or greater reliance on, multipurpose annual legumes as cover crops and/or green manures as high protein feed sources is a low-cost practice likely to improve the sustainability of these cropping systems. On steeply-sloping lands, the possible incorporation of a cover crop into the farming system may follow the conservation of vulnerable soils through the use of low cost technologies such as live barrier hedges (Ellis-Jones and Sims, 1995; Figures 1 and 2). Here, we define cover crops as (usually) a non-food crop, often a legume, grown in a cropping system to the benefit of subsequent food crops either through reducing the vulnerability of soil to erosion or to enhance its fertility. Our aim in this paper is to consider how we can provide a generic method of selecting potential legume cover crops species for different hillside cropping systems world-wide.

Selecting cover crops for different hillside environments

Legume cover crops are currently grown in a variety of cropping systems world-wide covering a wide range of cropping environments. The complex task of successful intervention with cover crop technologies into different traditional farming practices requires a clear understanding of the growth and development of different cover crops in order to match potential cover crop species to new target environments. In particular, selecting a legume cover crop that is well adapted to climate and management conditions is thought to be the first and most important decision (Frye *et al.*, 1988). A cover crop species can be considered to be adapted to an environment if it flowers and sets seed within the time constraints imposed by the environment in order to: first, provide seed for the next season's sowing or to regenerate naturally; and second, provide an additional food source from cover crops with edible seed, for example, faba bean, cowpea and some lupins. A better understanding of the effect of environment on the rates of development of legume cover crops is, therefore, a necessary first step in selecting cover crops for different target hillsides.

Effects of environment on the rate of development of crops

Crop development strictly involves a cellular change at the plant apex; the most common example being the transition from a solely vegetative state during which only leaves are initiated at the apex to a reproductive state during which floral initials are formed. Examples of such a developmental event include the time of the double ridges stage in wheat and the time of tassel initiation in maize. However, it is more common in legumes to define the main development stage as the time when the colour of the first flower is first visible, which is referred to simply as flowering. Much is known about the effects of environment on the development of annual food crops. In contrast, few studies have quantified the effects of environment on time to flowering in potential cover crop legumes. Thus, we first consider how the effects of environment on the rate of progress to flowering in annual cereals and legumes is modelled. Then, these quantitative techniques are applied to legume cover crop species.

Two aspects of environment control the time of flowering in crops; temperature and photoperiod (Roberts and Summerfield,

Figure 1. The thick mulch formed by Mucuna pruriens *grown between live barriers.*

Figure 2. Mucuna ana *provides off-sesson ground cover after a maize crop.*

1987). Models have been formulated which describe the rate of progress from sowing to flowering ($1/f$, given by the reciprocal of the time from sowing to flowering, f) as linear additive functions of each of temperature and photoperiod (Roberts and Summerfield, 1987). Between a base temperature (at and below which $1/f = 0$) and an optimum

Selecting a legume cover crop that is well adapted to climate and management conditions is the first and most important decision

The potential adaptation of a range of legume cover crops to any particular hillside environment can now be examined using the cover crop development models in order to provide advice for local field trials

temperature (at which 1/f is maximal) the combined response to temperature and photoperiod may be described by three equations:

a thermal plane wherein

$$1/f = a + b\,\mathrm{T} \qquad (1)$$

a photothermal plane wherein

$$1/f = a' + b'\,\mathrm{T} + c'\,\mathrm{P} \qquad (2)$$

a plane of maximum photoperiod delay

$$1/f = d' \qquad (3)$$

where T is mean pre-flowering temperature (^{o}C) and P is mean pre-flowering photoperiod (h d^{-1}) and a, b, a', b', c', and d' are genotypic-specific coefficients. Once the value of the six coefficients are known for a particular genotype, then the model can be used to predict the time of flowering for that genotype in other environments. This model of crop development has provided robust predictions of the rate of crop development in 16 different crop species to date (Summerfield *et al*., 1996).

Effects of environment on the rate of development of cover crops

The photothermal requirements of most potential legume cover crop species are not known, and the values of the coefficients of equations (1), (2) and (3) have not been defined. Exceptions are for those multipurpose annual legume crops principally used for food, such as faba beans, pea and cowpea for which coefficient values have been published (details in Keatinge *et al*., 1996).

The values of the genotypic-coefficients may be estimated using a small number of carefully-selected controlled environments. Predictions of the time to flowering are then tested using field trials on different hillside slopes. We collected seeds of eleven species of legume cover crops from different hillside locations world-wide. In addition, two varieties of *V. faba* from different ecological backgrounds in the Andes and the Himalayas were collected (Table 1).

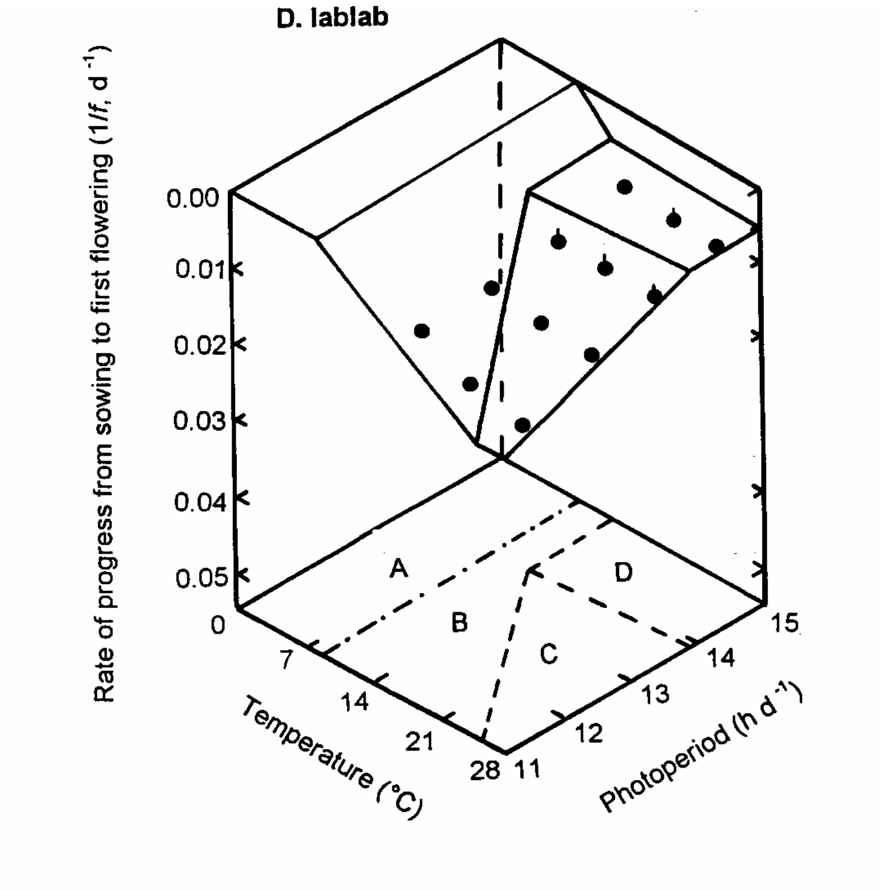
Seeds of each cover crop were planted in a factorial combination of three temperatures and four photoperiods. The plants were inspected daily and the time from sowing to flowering, and from flowering to the appearance of the first mature pod, was recorded for each cover crop species in each of the 12 environments. In general, the time from sowing to flowering was shorter at warmer temperatures for all species grown at a given photoperiod. However, for some temperate species flowering was progressively later at the very warm temperatures (e.g. *L. mutabilis*) and an optimum temperature for this species was identified (22^{o}C). The time of flowering was earlier as photoperiod increased for more temperate species (eg *Vicia faba*) grown at a given temperature. This is a response typical of ‘long-day’ species. However, for more tropical species (e.g. *Dolichos lablab*), the time of flowering was progressively delayed as photoperiod increased; a response typical of ‘short-day’ species. The time of flowering of *Lupinus mutabilis* was not affected at all by differences in photoperiod. Thus, for this ‘day neutral’ genotype, flowering time was solely determined by temperature (equation (1)).

The duration from flowering to the appearance of the first mature pod was also examined in each environment. This duration decreased at warmer temperatures, but was not affected by photoperiod in any of the 11 cover crop species investigated. Hence, duration from flowering to podding was only affected by temperature and was described by equation (1).

A detailed description of these results and the values of a, b, a', b', c', and d' for each of these species or genotypes are given in Keatinge *et al.* (1998), but an example for *Dolichos lablab* is presented in Figure 3.

Table 1. List of common (and scientific) names of the cover crop species investigated.

Temperate species	Tropical species
faba bean, Bolivia (*Vicia faba*)	velvet bean (*Mucuna pruriens*)
faba bean, Nepal (*Vicia faba*)	stylo (*Stylosanthes hamata*)
persian clover (*Trifolium resupinatum*)	jack bean (*Canavalia ensiformis*)
bitter lupin (*Lupinus mutabilis*)	sunn hemp (*Crotalaria juncea*)
woolly pod vetch (*Vicia dasycarpa*)	kudzu (*Pueraria phaseoloides*)
vetch (*Vicia sativa*)	lablab bean (*Dolichos lablab*)



Models of the effects of temperature and photoperiod on the rate of development of food crops have been successfully applied to legume cover crop species

Figure 3. Photothermal flowering responses of Dolichos lablab. *The distances of the observed points from the fitted response surfaces are shown by vertical lines extending above or below the symbols. Further details in Keatinge* et al.*, 1998.*

Table 2. Comparison of duration from sowing to flowering predicted using the cover crop development models with the duration observed in field trials for three cover crop species.

Species	Location	Sowing date	Days to flowering	
			Observed	Predicted
M. pruriens	Lumle, Nepal	19/07/96	138	160
	Namulonge, Uganda	16/09/96	48	41
C. juncea	Lumle, Nepal	19/07/96	160	152
	Namulonge, Uganda	16/09/96	65	66
V. faba (Bolivia)	Kabale, Uganda	18/09/96	65	70
	Lumle, Nepal	18/12/96	94	87

Model predictions of time to flowering showed good agreement with observations made in field trials in different hillside locations. For example, predictions for *M. pruriens*, *C. juncea*, and *V. faba* (Bolivia) presented in Table 2 were all reasonably close to the observed time of flowering; the maximum difference was 22 days for a duration of 138 days.

The use of cover crop development models as an aid to planning field trials

It is now possible to combine these cover crop development models with climate records for different hillside locations in order to predict the time of flowering and pod maturity for each cover crop species. The inputs required for this exercise are: the values of the coefficients of equations (1) and (2) (and in some species equation (3)); daily records of minimum temperature, maximum temperature, and rainfall from a local meteorological station; and the daily photoperiod calculated from latitude. Criteria for the time of sowing and the maximum length of the cover crop season (for example, defined by rainfall availability, or by the time between existing food crop seasons) are also needed. Then, the time of flowering and pod maturity is calculated using the model and whether or not the cover crop is able to flower and set seed within the available growing season is determined. Many model runs with different cover crops, or using different sowing dates, may be easily undertaken for different locations. As a result, cover crops that are not adapted to the particular hillside environment of interest can be identified and these species eliminated from subsequent field trials at this location. We are currently using such a simulation study to identify potential legume cover crop species adapted to four hillside locations: in Nepal, Honduras, Bolivia and Uganda.

Conclusion

Knowledge of the adaptation of potential cover crops to the environment is important when considering different potential legume cover crop species as a low-cost technology to counter soil erosion and decline in soil fertility in hillside cropping systems. Existing models of the effect of temperature and photoperiod on the rate of development of food crop species provide the basis for examining the potential adaptation to environment of cover crop species. Such crop development models have now been derived for some of the more common legume cover crop species. These models should permit the potential adaptation of many different cover crop species to be examined for a given hillside environment to permit a more closely defined subset of cover crop species to be recommended for local field trials.

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Acknowledgements

This paper is an output from project R6447 partly funded through the Natural Resources Systems Programme of the UK Department for International Development (DFID) for the benefit of developing countries. The views expressed are not necessarily those of DFID.

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Erratum

Livesley, S.J., Gregory, P.J. and Buresh, R.J. (1997) Approaches to modelling root growth and the uptake of water and nutrients. *Agroforestry Forum* **8**(2): 24-26.

The authors regret that because of an error in calculations, the root length density data in this article were presented an order of magnitude too large. However, this does not alter the general conclusions of the paper.

IUFRO meeting announcement

International symposium on multi-strata agroforestry systems

CATIE, Turrialba, Costa Rica
22-27 February 1999

Objectives

- To document and synthesize available biophysical and socio-economic results (and methodologies), from the investigation, development and promotion of traditional and new multi-strata agroforestry systems with perennial crops.
- To promote individual/institutional cooperation in existing/new research programmes on multi-strata agroforestry systems, including collaboration between members of different IUFRO groups.
- To prepare recommendations for future research priorities on this topic to be presented during the sessions of the Agroforestry Group 1.15 at the next IUFRO congress in Malaysia in August 2000.

Themes

- coffee, cocoa or tea shade systems
- Damar, rubber and other agroforests of SE Asia
- home gardens
- species and management diversity in multi-strata agroforestry systems
- tree-crop interactions
- socio-economic interactions
- system design and management for IPM, ecological stability and reduced external effects
- design and management of multi-strata systems for improved resource utilization and production stability/ sustainability (including economic stability and risk management)
- research and development methodologies including experimental design and sampling procedures, methods for studying specific interactions, system analysis and modelling*

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For more information, please contact: Agroforestry Workshop Secretariat, Attn. Celia Lopez, CATIE, Apto. 7170, Turrialba, Costa Rica. Tel: +506 556 1789 or +506 556 7830; fax: +506 556 1576 or +506 556 7766; email: celial@catie.ac.cr

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*The meeting will be held simultaneously with IUFRO group 4.11 on ‘Long-term observations and experiments in forestry and agroforestry’: some joint activities are being organised to promote discussion of research methodologies.

About *Agroforestry Forum*

Agroforestry Forum is the newsletter of the UK Agroforestry Research Forum edited by Fergus Sinclair and produced by Michelle Jones at the University of Wales, Bangor. It exists to facilitate rapid exchange of information and opinion amongst researchers active in the agroforestry domain. It is an informal newsletter that allows contributors scope to share and explore new ideas and data. The views expressed in the newsletter are the authors' and do not necessarily reflect those of the Editor, the Forum or any institutions that the authors may belong to. Articles are reviewed in terms of their scientific merit and interest to our readership. We particularly welcome concise articles breaking new ground in agroforestry. Notes on research techniques, reports of progress in longer term experiments and topical review articles are also published. The use of diagrams and photographs is encouraged as well as fresh and lively writing. Short communications that challenge conventional perceptions will be given priority. *Articles marked 'DO NOT CITE' should not be cited without prior consultation and agreement with the author(s).*

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This special issue was eo-edited by Fergus Sinclair and Morag McDonald

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Copy date for next issue is 15 July 1998

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