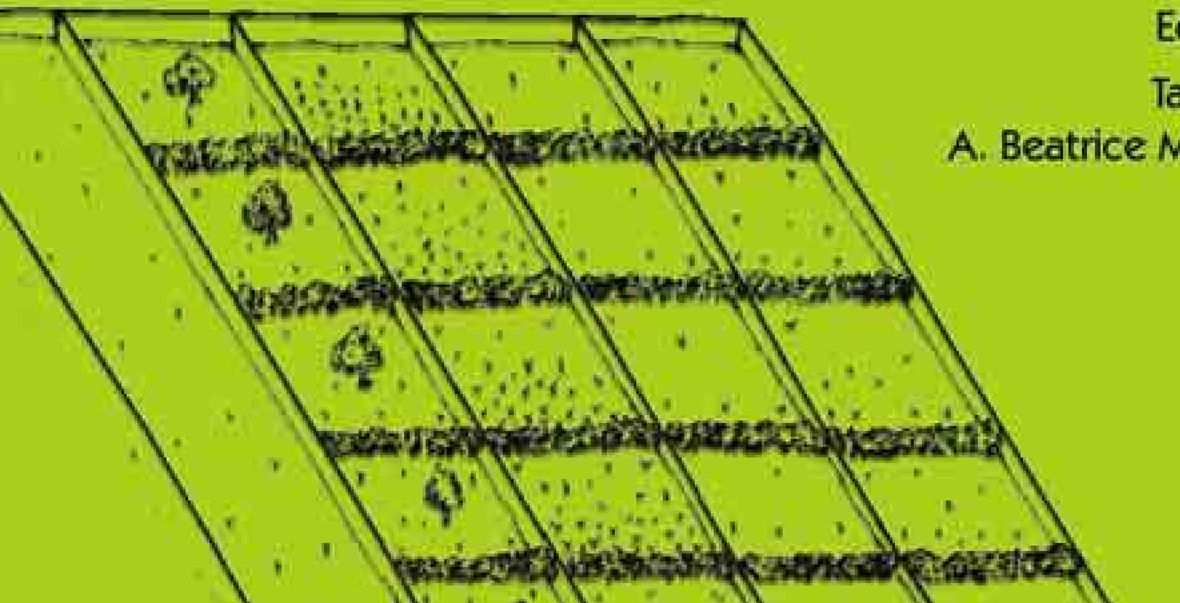
Impact of Contour Hedgerows: A Case Study



Editors

Tang Ya

A. Beatrice Murray

Godavari ICIMOD

Focus on Godavari #3

About ICIMOD

The International Centre for Integrated Mountain Development (ICIMOD) is an independent 'Mountain Learning and Knowledge Centre' serving the eight countries of the Hindu Kush-Himalayas – Afghanistan, Bangladesh, Bhutan, China, India, Myanmar, Nepal, and Pakistan – and the global mountain community. Founded in 1983, ICIMOD is based in Kathmandu, Nepal, and brings together a partnership of regional member countries, partner institutions, and donors with a commitment for development action to secure a better future for the people and environment of the Hindu Kush-Himalayas. The primary objective of the Centre is to promote the development of an economically and environmentally sound mountain ecosystem and to improve the living standards of mountain populations.

Focus on Godavari

The series '**Focus on Godavari**' will feature information on topics related to the activities of the ICIMOD Demonstration and Training Centre, Godavari. The topics will include background information about technologies, species, and general approaches for integrated mountain development; results of trials and recommendations of appropriate species and technologies; and reports on outreach and training activities both on and off site.

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#4 Performance and Selection of Nitrogen-Fixing Hedgerow Species
#5 Perennial Cash Crops for Mountain Areas (forthcoming)

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A Case Study

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Focus on Godavari #3

International Centre for Integrated Mounain Development
Natural Resources Management Programme
Kathmandu, Nepal
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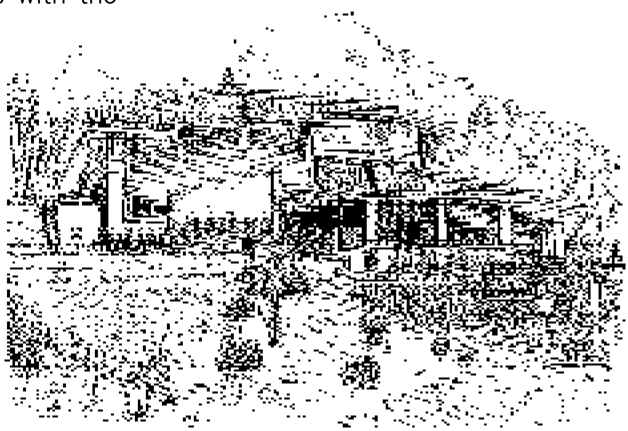
Foreword
Focus on Godavari

The International Centre for Integrated Mountain Development (ICIMOD) was established in 1983 amidst increasing concern about environmental degradation and poverty in the Hindu Kush-Himalayan (HKH) region. Its area of mandate is the Hindu Kush-Himalayan region (all or part of the eight countries Afghanistan, Bangladesh, Bhutan, China, India, Myanmar, Nepal, and Pakistan). ICIMOD's activities focus on the reduction of poverty and the conservation of the natural resource base.

The HKH sustains a population of about 150 million peoples of diverse cultures, the great majority of whom depend upon agriculture as their main source of livelihood. The well-being of mountain peoples is to a great extent determined by the state of mountain agriculture and the potential for economic improvement. Equally, the security of the livelihoods of future generations depends on ensuring that use of natural resources is sustainable, and that the environment is maintained and not degraded.

Mountain agriculture in the HKH is slowly transforming from traditional farming of cereal crops to mixed farming of high-value cash crops and animal husbandry for income. This agricultural transformation poses new challenges, and farmers can no longer rely solely on the wealth of indigenous knowledge acquired over generations. New choices of appropriate crops for the specific local mountain conditions, choices of appropriate methods for land use intensification without upsetting the sensitive balance of fragile mountain ecosystems, new methods of extending agricultural practices to marginal lands that stabilise rather than destroy, increasing the water supply through water harvesting and irrigation, new ways of improving crop productivity and quality without negatively affecting the environment, are technologies that must be tried, tested and integrated within existing farming systems. Many improved technologies have been developed for and promoted in mountain areas with the aim of reducing poverty and conserving the environment. But as mountain farmers have very limited resources, they are risk adverse and will not invest in an improved technology unless they can assess it carefully first. For technologies to be adopted by farmers they must first be tested and demonstrated in an accessible and convincing way.



ICIMOD established its Demonstration and Training Centre at Godavari, on the southern slopes of the Kathmandu Valley, in March 1993, following the generous provision of 35 hectares of land by His Majesty's Government of Nepal in November 1992. The site provides a place where different technologies and (farming) practices useful for sustainable development can be tested, selected, and demonstrated; where farmers and those who work with them can be trained; and which can serve as a repository for plant germplasm resources and associated floral and faunal biodiversity. Activities in an integrated agricultural system are by their nature cross-cutting and often interactive and interdependent. The activities at the Godavari Centre are linked within a holistic approach that covers a broad range of the possibilities for livelihood – and quality of life – improvement of mountain farmers.

Over the years a large amount of information has been accumulated related to the activities at the Godavari Centre. It includes background information about technologies, species, and general approaches for integrated mountain development; results of trials and recommendations of appropriate species and technologies; training materials; and many others. The series '**Focus on Godavari**' has been developed to provide a platform for formal publication and wider dissemination of this information. We hope that these books will prove useful to a wide audience, and help provide information that will benefit mountain farmers. We welcome feedback from our readers and new ideas for the series.

J. Gabriel Campbell
Director General, ICIMOD

Preface

Severe soil erosion and declining soil fertility are widely regarded as major problems threatening the sustainable use of sloping agricultural land in the Hindu Kush-Himalayan region. Each year, large amounts of soil are lost from sloping land in the Hindu Kush-Himalayan (HKH) region, mainly as a result of water erosion. One of the most effective ways that farmers have found to increase the stability and workability of sloping cropland has been to build terraces, but traditional terracing does not always prevent land degradation, especially when extended to steeper slopes and more marginal land. Sloping agricultural land technology (SALT), also known as contour hedgerow intercropping (agroforestry) technology (CHIAT), was developed some twenty years ago as a new approach that combines the strengths of terracing with the strengths of natural vegetation to stabilise sloping land and make it available for farming. In this system, dense hedgerows of fast growing perennial woody tree or shrub species, usually nitrogen-fixing species, are planted along contour lines to create a living barrier that traps sediments and gradually transforms the sloping land to terraced land. When successful, the technique simultaneously reduces soil erosion and improves soil fertility.

SALT or CHIAT was originally developed for use in tropical countries. In the early nineteen-nineties, ICIMOD, in collaboration with a number of national institutions, introduced the contour hedgerow technology to six countries in the Hindu Kush-Himalayas to assess its feasibility in the region, mostly under the project on Appropriate Technologies for Soil Conserving Farming Systems funded by the Asian Development Bank. Two experiments were set up at ICIMOD's Trial and Demonstration site at Godavari to investigate different aspects of SALT and its usefulness and applicability in the cooler climate of the Himalayan mid-hills. The studies showed clearly that SALT can be used effectively in subtropical and temperate regions, not only in the tropical regions where it was first developed. The method can help facilitate sustainable management of sloping cropland and contribute to sustainable mountain agricultural development and environmental conservation by reducing soil erosion and increasing productivity, opening up the possibility of continuous cultivation of sloping croplands.

This book describes the experiments, and their results and implications. I hope it will prove useful for farmers and development workers considering using SALT to slow degradation and increase the productivity of sloping land, and also provide an incentive for the increased application of this approach in the HKH region. Many of the plots established for these trials are still being used to demonstrate the technology and can be viewed at ICIMOD's Demonstration and Training Centre at Godavari. They provide a convincing example of the potential value of the approach.

Eklabya Sharma
Programme Manager
Integrated Programme on
Natural Resource Management

Executive Summary

Severe soil erosion and declining soil fertility are widely regarded as major problems threatening the sustainable use of sloping agricultural land in the Hindu Kush-Himalayan region. Simple terracing is widely used to control soil erosion, but it is not always effective and increasingly less so as agriculture is extended to ever more and steeper slopes in the attempt to increase production. There are few effective methods available in the region to control soil erosion and improve soil fertility simultaneously. Sloping agricultural land technology (SALT), or contour hedgerow intercropping (agroforestry) technology (CHIAT), using nitrogen-fixing plants has shown potential in tropical regions in controlling soil erosion and in improving soil fertility of sloping agricultural land. In this system, the terraces are developed by planting dense hedgerows of fast growing perennial woody tree or shrub species, usually nitrogen-fixing species, along contour lines thus creating a living barrier that traps sediments and gradually transforms the sloping land to terraced land. The hedgerows lining the terrace help improve soil fertility through nitrogen fixation at the roots and incorporation of the hedgerow trimmings into the soil. However, competition is sometimes observed between the hedgerows and the crops in the alleys; fear of this is thought to have inhibited widespread adoption of the technology by farmers in tropical regions.

Two experiments were set up at ICIMOD's Trial and Demonstration site at Godavari to investigate different aspects of SALT and its usefulness and applicability in the cooler climate of the Himalayan mid-hills. The first experiment, from 1995 to 2001, investigated the impact of hedgerows on soil erosion and soil fertility; the second, from 1998-2001, looked at the potential competition between hedgerows and crops for soil nutrients and soil moisture. The results of these experiments are described in this book: Chapter 1 provides an overview of SALT and the experimental set up at the Godavari site; Chapter 2 describes the impact of hedgerows on soil erosion; Chapter 3 the impact of hedgerows on soil fertilty; Chapter 4 the extent of hedgerow-crop competition for nutrients; and Chapter 5 the extent of hedgerow-crop competition for soil moisture.

The impact of hedgerows on soil erosion and soil fertility was tested using five different treatments: one with normal farming practice without hedgerows, and four with two different hedgerow species, different cropping approaches, and with or without application of organic fertiliser for the annual crops.

Soil erosion was evaluated from sediment concentration in runoff and total runoff. The contour hedgerows were very effective in reducing soil erosion to a very low level, with a marked impact from the second year of planting and a reduction in soil loss by 80-99% from the fifth year on, suggesting that hedgerows have the potential to facilitate continuous cultivation of sloping cropland.

Soil fertility was monitored through annual collection and analysis of soil samples from a depth of 0-30 cm. The hedgerows did not improve soil fertility in the experiments with freshly planted hedgerows as evaluated in terms of parameters like organic matter and nitrogen. This was partly because the soils started with a high level of most soil nutrients in a fertile forest soil, rather than a degraded agricultural soil, and partly because of the low production of fresh biomass by the hedgerows. The hedgerows did help reduce loss of available potassium and in the long run would probably help maintain soil fertility. One type of land use management, planting of peach trees in the alleys with intercropping of vegetables, did increase the availability of several nutrients, especially available phosphorous and potassium.

Hedgerow-crop competition for nutrients and soil moisture was assessed using sample sites with or without cultivation of crops in an established hedgerow alley. Soil samples were collected at three different distances from hedgerows and analysed for soil nutrients. Soil moisture was assessed from measurements at five-day intervals of soil tension at four different depths at each of three different distances from the hedgerows. The potential competition for water between hedgerow and crop was investigated by modelling.

The results indicate that there was no competition between hedgerows and crops for soil nutrients; the soil content of most nutrients was higher closer to the hedgerows suggesting that the hedgerows actually improved the soil nutrient status. There was competition between the hedgerows and crops for soil moisture in the dry season. Interestingly, although yield of radish (the dry season crop) was higher closer to the hedgerows, yield of maize (the monsoon crop) was slightly lower, indicating that factors other than nutrient status affect crop yield, and that the effects on different crops are not uniform.

The study showed clearly that SALT can be used effectively in subtropical and temperate regions, not only in the tropical regions where it was first developed. The method can help facilitate sustainable management of sloping cropland and can contribute to sustainable mountain agricultural development and environmental conservation by reducing soil erosion and increasing productivity, opening up the possibility of continuous cultivation of sloping croplands. In order for the technology to achieve its full potential, other, possibly more appropriate, hedgerow species need to be tested, and more investigations of different crops and their yields need to be carried out to identify optimum combinations for applications in temperate and subtropical areas of the HKH.

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The authors would like to thank Dr. Tej Partap, former Head Mountain Farming Systems Division, ICIMOD, for his continued support; the Asian Development Bank for financial support to the project on Appropriate Technologies for Soil Conserving Farming Systems, under which much of this research was undertaken; Mr. Suraj B. Thapa, Farm Manager for generous assistance and support; Mr. Jivan Tamang for field data collection; Mr. Prabakhar B. Shah for arranging the chemical analysis of the soil samples collected from 1995 to 1997; Dr. Zhang Bin and Mr. Zong Haihong of the Nanjing Institute of Soil Science, Chinese Academy of Sciences, for chemical analysis of the soil samples collected in 1998-2001 and for assisting in the design of the experiments on competition and analysis of soil samples, and Dr. Sun Hui of the College of Environment, Sichuan University, for statistical analysis. We thank Mr. Dharma R. Maharjan of ICIMOD's Publications Unit for the preparation of figures and the layout design of this publication.

Acronyms and Abbreviations

ATSCFS	Appropriate Technologies for Soil Conserving Farming Systems
CEC	cation exchange capacity
CHIAT	contour hedgerow intercropping (agroforestry) technology
ECEC	effective cation exchange capacity
HKH	Hindu Kush-Himalaya(s/n)
HYV	high yielding variety
IBSRAM	International Board for Soil Research and Management
ICIMOD	International Centre for Integrated Mountain Development
SALT	sloping agricultural land technology

Chapter 1

Erosion and Degradation of Sloping Agricultural Land and Technologies for Mitigation

Tang Ya and A. Beatrice Murray

Introduction

Pressure on land in mountain areas has increased considerably in recent years as a result of a variety of factors including the increasing human population, the continuing loss of cropland to other uses, and erosion and degradation of existing crop land. It is both the cause and the result of a general degradation of the environment. In the Hindu Kush-Himalayan (HKH) region this pressure has led to forest clearance and the intensified use of sloping land for agriculture. This has led to a further deterioration of the resource base with a general decline in soil fertility, an increase in soil erosion, and an increase in the number of landslides and landslips.

Soil erosion and degradation are widely regarded as a major threat to sustainable growth in agricultural production in both developed and developing countries. Soil erosion is one of the most important factors contributing to land degradation and the decline in soil fertility of sloping croplands. Farmers in the mountains are facing problems of land degradation and low productivity as a result of topsoil loss and nutrient leaching. Each year, large amounts of soil are lost from sloping land in the Hindu Kush-Himalayan (HKH) region, mainly as a result of water erosion. Especially the nutrient rich topsoil is eroded from this marginal agricultural land, damaging the productive capacity of the land and impacting on stream water quality. In India, for example, water erosion leads to an annual loss of some 6,000 million tonnes of soil containing nutrients equivalent to five and a half million tonnes of NPK, much of this from the northern mountainous areas (Bosu and Sivanappan 1989). In China, the annual soil loss from erosion is 5,000 million tonnes, containing nutrients equivalent to 40 million tonnes of NPK (Niu Chonghuan; Wang Lixian 1992). The eroded soil that is left behind contains coarser particles that are relatively low in nutrients and less capable of absorbing water. Water flows faster across such fields, causing more damage. Surface erosion is a natural process, but soil erosion has increased drastically as a result of inappropriate land use and management, and the current amount exceeds the natural rates many times.

One of the most effective ways that farmers have found to increase the stability and workability of sloping cropland has been to build terraces. Bench terraces can greatly reduce erosion, increase water infiltration, and make the land easier to manage. Many traditional agricultural systems have developed extremely effective terraces that ensure the long-term stability of the land, and terracing is a common practice in many areas of the HKH. Terraces have occasionally been promoted as the panacea to all erosion problems on sloping agricultural land. However, although they can be effective, there are also clear limitations. Terracing alone cannot be used to stabilise sandy and coarse-textured soils or very steep slopes. When marginal areas are cleared of vegetation and terraced, there is a danger that they will have to be abandoned after several years cultivation as a result of severe degradation and reduced soil fertility if proper and effective measures are not taken. Nutrients will be leached out, and without stabilising permanent vegetation the terraces may simply slip down the hillside.

Sloping Agricultural Land Technology

Sloping agricultural land technology (SALT), also known as contour hedgerow intercropping (agroforestry) technology (CHIAT), was developed some twenty years ago as a new approach that combines the strengths of terracing with the strengths of natural vegetation to stabilise sloping land and make it available for farming. In this system, the terraces are developed by planting dense hedgerows of fast growing perennial woody tree or shrub species along contour lines (Partap and Watson 1994). The hedgerows create a living barrier that traps sediments and gradually transforms the sloping land to terraced land forming a 'bioterrace'. The final terrace has almost all the functions of a hand-cut terrace but is lined on both sides by the hedgerows. In general, the hedgerows are established using fast growing nitrogen-fixing species. These have the added potential to improve soil fertility, both directly through nitrogen fixation at the roots, and indirectly through incorporation of the hedgerow trimmings into the soil in the alleys between the hedgerow plants. The hedgerows must be pruned regularly to prevent shading of the crops and to make the biomass available, this can also offer additional benefits through the production of fuel and/or fodder.

SALT or CHIAT was originally developed for use in tropical countries, where it has shown considerable potential for controlling soil erosion and improving the fertility of sloping agricultural land. There are numerous research papers on the potential or actual effect of hedgerows in the tropics (e.g., Laquihon and Watson 1986; Lal 1988; Paningbatan 1990; Kiepe and Young 1992; Kang et al. 1993; Tacio 1993; Kiepe 1995), but there are far fewer reports of the technology being used in other areas, although the method has proven effective in reducing soil erosion, improving soil fertility, and enhancing crop yield in subtropical China (Sun Hui et al. 1999a, 1999b, 2001; Tang Ya et al. 2001).

In the early nineteen nineties, the International Centre for Integrated Mountain Development (ICIMOD), in collaboration with a number of national institutions introduced contour hedgerow technology to subtropical and warm temperate areas of the HKH region. SALT was introduced, tested and demonstrated on farmers' lands in six countries in the Hindu Kush-Himalayas – Bangladesh, China, India, Myanmar, Nepal and Pakistan – to assess its feasibility in the region, mostly under the project on Appropriate Technologies for Soil Conserving Farming Systems funded by the Asian Development Bank. This publication focuses on the results of the tests at the main test site in Nepal.

Despite its great appeal and potential, SALT is often viewed with suspicion by farmers. During the course of testing, demonstration, and extension, a number of concerns appeared. A particular concern voiced by farmers is that of possible competition between the hedgerows and crops for nutrients. Competition between hedgerows and crops in alleys has been observed in tropical regions, where it was regarded as one of the main causes for poor adoption. However, the real extent of such competition, and the question of whether the benefit of the hedgerows outweighs any possible negative impact, can only be determined through proper long-term trials.

SALT Trials at the Godavari Trial and Demonstration Site

A series of trials have been carried out since 1993 at ICIMOD's Godavari Trial and Demonstration Site to develop, test, and demonstrate various aspects of SALT. The establishment of hedgerows and selection and performance of hedgerow species is described in another book in this series (Tang Ya 2004a). Once hedgerows had been established, it was necessary to assess their effectiveness in soil conservation and soil fertility improvement, as well as to investigate the extent of nutrient and moisture competition between hedgerows and crops. Two experiments were carried out at the ICIMOD site. The first, from 1995 to 2001, investigated the impact of hedgerows on soil erosion and soil fertility; the second, from 1998-2001, looked at the potential competition between hedgerows and crops for soil nutrients and soil moisture. The results of these experiments are described in this book.

The study site

The study was conducted at ICIMOD's Godavari Trial and Demonstration Site, which lies some 15 km from Kathmandu in the south-east corner of the Kathmandu Valley at the foot of the Phulchoki Mountain, the highest mountain bounding the Kathmandu Valley. The area lies in the Himalayan mid-hills of Nepal. The site is described in more detail in the first book in this series (Tang Ya 2004b).

The climate is subtropical monsoon with an annual average rainfall of around 2000 mm and distinct rainy and dry seasons; 80% of the precipitation falls during the monsoon (June-September). The mean annual temperature during the trials was 15.9°C, with the coldest month in January and the hottest month in June (Figure 1.1).

The experiment was carried out on newly-cleared land in an area that had been degraded forest reduced to shrub land with a few trees. The site lies at 1540-1800m and is sloping with gradients of 26-31° (45.5-60%) with a north-northeast aspect. The soil is sandy loam with a high content of organic matter and nitrogen, moderate available potassium and phosphorous, and very acidic. The major biophysical characteristics are summarised in Table 1.1. The land had not been cultivated prior to establishing the hedgerows.

Hedgerows

The background and basic methodology of SALT is described elsewhere (Partap and Watson 1994; Tang Ya 1999) and the results obtained with different hedgerow species in another book in this series (Tang Ya 2004a).

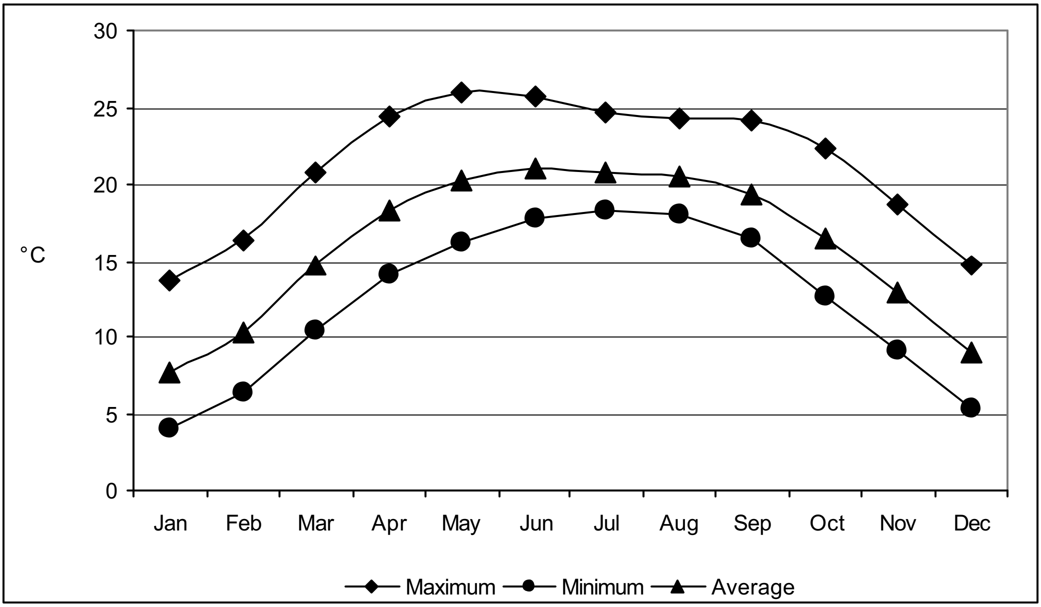

Figure 1.1: Mean monthly maximum, minimum, and average temperatures, 1996-2000

Table 1.1: Biophysical characteristics of the Godavari site	
Latitude	27°35'19" to 27°35'41"N
Longitude	85°23'16" to 85°23'44" E
Altitude	1540-1800 masl
Slope gradient	26-31° (45.5-60%)
Temperature (1996-2000)	
• Average annual maximum	21.3°C
• Average annual minimum	12.4°C
• Average annual mean	15.9°C
• Mean hottest month (June)	21.0°C
• Mean coldest month (January)	7.6°C
• Absolute minimum (18 January 1998)	-0.5°C
• Absolute maximum (10 June 1998)	33.8°C
Mean annual rainfall (1996-2001)	2062 mm, 80% between June and September
Soil	
• Texture	clay loam to sandy and silty clay loam
• Depth	25-100 cm
• pH	4.2-5.5
• Organic matter content (0-30 cm)	8.3%
• Total nitrogen content (0-30 cm)	0.29%
• Available K	238.6 ppm
• Available P	7.1 ppm
Natural vegetation	mixed deciduous and evergreen broadleaved forest

Hedgerows were established by transplanting seedlings in a double row along the contour lines of a slope at a density of about 20 plants per metre (10 per metre single row). The double rows occupied a strip of about 0.5m and were separated by an alley with a width determined by the slope and experiment. Any plants that died were replaced with fresh seedlings at the start of the next monsoon season. With time, the topsoil washed down from the alleys above built up behind the hedgerows below to form natural terraces.

The hedgerows were pruned once in the first year after planting and one to three times a year thereafter depending on growth. The fresh trimmings were spread as mulch in the alleys. The twigs were placed within the double hedgerows.

The alleys were used for growing annual crops and/or fruit trees.

Experiments

Soil erosion and soil fertility

The first experiment was designed to assess the effect of hedgerows on soil erosion and soil fertility. Four different hedgerow treatments were tested with variations in the hedgerow species (*Alnus nepalensis* or *Indigofera dosua*), the use or omission of organic fertiliser, and the type of crop grown (annual crops or fruit trees with vegetables). Control plots were farmed without hedgerows according to local practice.

The hedgerows were planted in 1995; measurements were taken from 1996 to 2000.

Soil erosion was assessed from measurements of runoff and soil loss. Data were collected on a daily basis during the monsoon season and on an event basis during the dry season.

Soil fertility was assessed by chemical analysis of soil samples collected annually before planting of crops. The annual fresh biomass produced by the hedgerows and crop yield were also recorded.

Hedgerow-crop competition for nutrients and moisture

The second experiment was designed to assess the extent of competition between hedgerows and crops for nutrients and soil moisture.

The experiment was carried out on an established hedgerow intercropping alley. The hedgerows of *Alnus nepalensis* were established in 1993 by transplanting seedlings. By the time the experiment commenced in 1998, the alley between the hedgerows had become an almost level terrace.

There were two treatments each with three replicates: one with cultivation of crops and one without. The experimental plots for each treatment were 5m long and 3m wide and there was a 1m gap between treatments as a buffer area.

Nutrient competition was assessed by analysing the nutrient status of soil samples collected at three different distances from the hedgerows. Crop yield and fresh biomass production of the hedgerows were also measured. Data was collected for three consecutive years.

Soil moisture was assessed from measurements of soil tension at four different depths at each of three different distances from the hedgerows. Data were collected from May 1999 to January 2001. The potential competition for water between hedgerow and maize was investigated by modelling, using estimates of the water consumption of the plants.

Meteorological Data

A meteorological station was set up about 50m from the experimental plots. Air temperature, precipitation, evaporation, solar radiation, and sunshine duration were recorded manually on a daily basis, and on an hourly basis from an automatic weather station.

Results and Conclusions

The results of the soil erosion investigations are presented in Chapter 2, of the soil fertility experiments in Chapter 3, of the nutrient competition investigation in Chapter 4, and of the soil moisture competition experiments in Chapter 5.

Essentially, the results suggest that contour hedgerows are very effective in reducing soil erosion to a very low level and have the potential to facilitate continuous cultivation of sloping cropland. The hedgerows did not improve soil fertility in the experiments with freshly planted hedgerows, partly because the soils started with a high level of most soil nutrients, partly because of the low production of fresh biomass by the hedgerows. The hedgerows did help reduce loss of available potassium and would probably help maintain soil fertility in the long run.

There were higher levels of most soil macro-nutrients close to the hedgerows in the established terrace and there was no competition between hedgerows and crops for nutrients; but there was competition between the hedgerows and crops for soil moisture in the dry season. Interestingly, although yield of radish (the dry season crop) was higher closer to the hedgerows, yield of maize (the monsoon crop) was not, indicating that factors other than nutrient status affect crop yield, and that the effects on different crops are not uniform.

Contour hedgerow intercropping technology has a good potential for facilitating sustainable management of sloping cropland and can contribute to sustainable mountain agricultural development and environmental conservation by reducing soil erosion and increasing productivity, opening up the possibility of continuous cultivation of sloping croplands. In order for the technology to achieve its potential, other, possibly more appropriate, hedgerow species need to be tested, and more investigations of different crops and their yield need to be carried out to identify optimum combinations for applications in temperate and subtropical areas of the HKH.

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View of three replicate soil erosion plots, each with five different treatments (four with hedgerows, one without) in parallel strips as described in the following chapter.

Chapter 2

Effect of Contour Hedgerows of Nitrogen-Fixing Plants on Soil Erosion of Sloping Agricultural Land

Tang Ya and Gopal Nakarmi

Introduction

Sloping agricultural land technology (SALT), or contour hedgerow intercropping (agroforestry) technology (CHIAT) as it is also known, was developed some twenty years ago as a new approach that combines the strengths of terracing with the strengths of natural vegetation to stabilise sloping land and make it available for farming.

This chapter describes the results of trials to test the effectiveness of contour hedgerows of nitrogen-fixing plants *(Alnus nepalensis* and *Indigofera dosua)* in soil conservation of sloping agricultural land: i.e., the extent to which they could reduce erosion of soil from the slopes. The study focused on rainfall induced soil erosion as this is the principal source of erosion in the mid hills of Nepal; wind plays a far less important role.

Materials and Methods

Study site

The study was conducted at ICIMOD's Godavari Trial and Demonstration Site. The site characteristics are summarised briefly in Chapter 1. The experiment was carried out on newly-cleared land in an area of degraded forest with sandy loam soil.

Experimental design

The experiment consisted of five treatments, each with three replications, as follows.

Treatment 1 (T1) = Control – traditional practice of Nepalese farmers with up-and-down slope tillage operations and clean or weed-free cultivation of annual crops, without hedgerows but with application of organic fertiliser

Treatment 2 (T2) = As T1 – but with double hedgerows of *Alnus nepalensis* along slope contour lines and crop and weed residues and hedgerow clippings incorporated into the soil in the alleys between the double hedgerows

Treatment 3 (T3) = As T2 – without use of organic fertiliser

Treatment 4 (T4) = As T2 – but with hedgerows of *Indigofera dosua*

Treatment 5 (T5) = As T2 – but with peach trees planted in the hedgerow alleys intercropped with vegetables

Each experimental plot was 5m wide across the slope and 20m down the slope (0.01ha), plots were laid out side by side with galvanized iron plates separating them. The replicate plots were arranged as three groups of five different plot treatments with the order of treatments within the group determined by random sampling. The layout is shown in Figure 2.1.

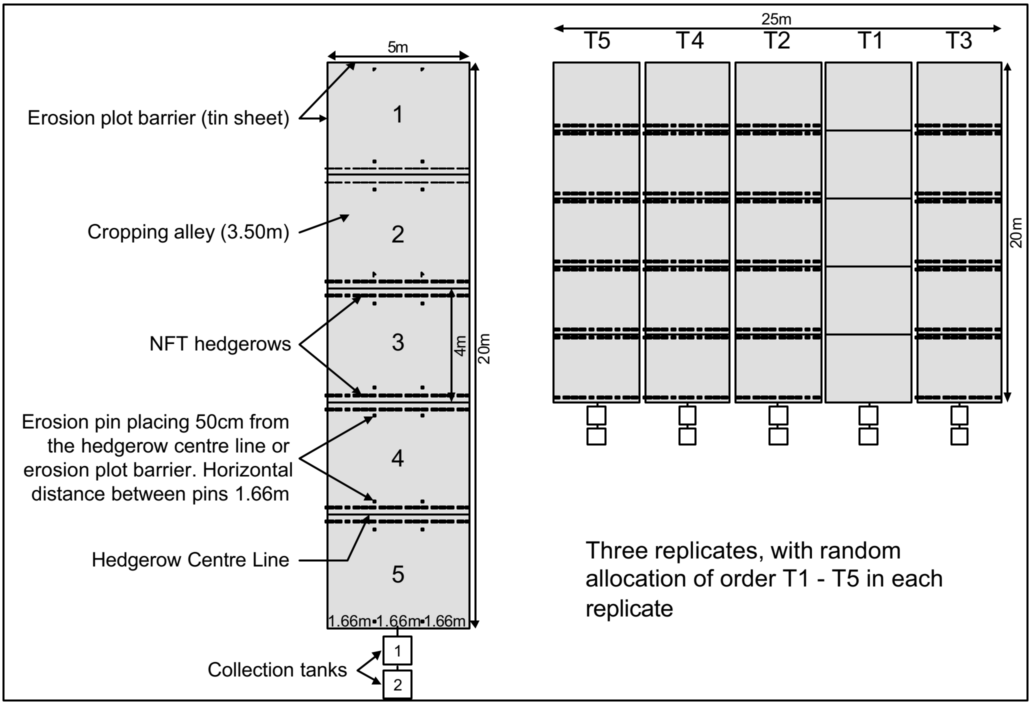

Figure 2.1: Layout of the research plot

The hedgerows were planted as five lines along contour lines at intervals of 4m down the slope: four double hedgerows with a single hedgerow at the bottom of the slope. Each double hedgerow was about 50cm wide and the intervening alleys were about 3.5m wide.

The hedgerows were established by transplanting seedlings using about 100 plants per 5m long double hedgerow. Each year any plants that had died were replaced with fresh seedlings. Planting of hedgerows was completed on 22 Jun 1995. The alleys were used for growing annual crops in T2, T3, and T4, and peach and vegetables in T5. The same crop was planted for the same cropping season in T1, T2, T3, and T4.

Management of the crops was similar except that no organic fertiliser was used in T3. The locally available concentrated organic fertiliser ‘kisan mal’ (3% N, 5% P_2O_5 and 2% K_2O) was applied throughout the experiment at a rate of 16t/ha once per cropping season (twice a year) for all treatments except T3. (Kisan mal is a concentrated organic fertiliser prepared from bone meal, chicken manure, and animal residues; the composition was confirmed by chemical analysis at the Soil Science Department of Tribhuvan University, Kathmandu.) The hedgerows were pruned once in 1996 and twice a year from 1997 onwards. The fresh trimmings were weighed and spread as mulch in the alleys. The twigs were placed within the double hedgerows.

Measurements

Measurements of surface runoff were carried out according to standard procedures (IBSRAM 1997). The surface runoff from each experimental plot was diverted through a gutter system into collection tanks. The first tank took all runoff water; a second tank received approximately 10% of any overflow from the first tank. The actual diverting coefficient was calibrated for each of the tanks. All the tanks were calibrated for volume calculated from the depth of water.

Data collection started on 26 June 1995, but the data for the first half year was not included in the calculations as the establishment activities caused frequent disturbances. The results reported here cover the period 1996 to 2000. Data for runoff and soil loss were collected on a daily basis during the monsoon season and on an event basis during the dry season. The height of the runoff collected in the tanks was recorded and the corresponding volume calculated with a computer programme.

Samples were taken for soil loss calculations when the water level in any one of the tanks reached or exceeded 5 cm. A sample volume of 500 ml was filtered in the field laboratory. Sediments were oven-dried and weighed. After recordings had been made, the tanks were emptied and cleaned in preparation for the next rainfall event.

A meteorological station was set up about 50m from the experimental plots. Air temperature, precipitation, evaporation, solar radiation, and sunshine duration were recorded manually on a daily basis, and on an hourly basis from an automatic weather station.

Results

Rainfall characteristics

The rainfall characteristics of total rainfall, seasonal distribution, and rainfall intensity have a direct effect on soil erosion and these aspects were studied in detail. The monthly rainfall data for 1996 to 2000 are shown in Figure 2.2; the total days with different amounts of rainfall in Table 2.1; the total hours with different rainfall rates in Table 2.2, and the total annual rainfall and five highest daily rainfall events in Table 2.3.

The total number of days in a year with rainfall ranged from 178 to190. Of these, between 45 and 59 days per year had less than 1 mm of rainfall; these days were excluded from the analysis because of the negligible impact of such a small amount of rain on soil erosion. The total number of days in a year with rainfall over 1 mm ranged from 125 to 136 (Table 2.1), and the total number of hours with rain from 857 to 955 (Table 2.2). (The number of hours with rain in 2000 was excluded from the average as a result of problems with the data logger which led to uncertainty in these readings). Overall there was greater variation in the number of hours with rainfall than in the number of days with rainfall. The total annual rainfall ranged from 1,938 to 2,245 mm (Table 2.3), and the highest rainfall in a single day from

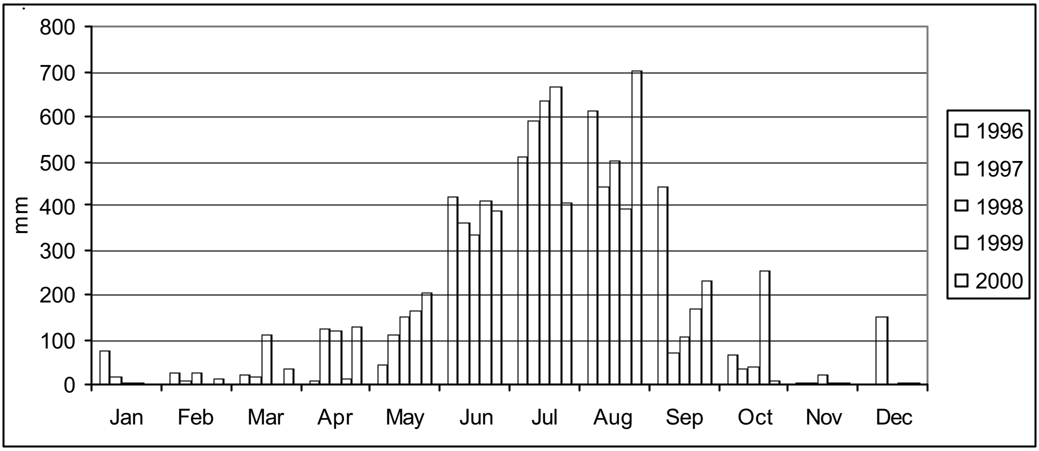

Figure 2.2: Monthly rainfall, 1996-2000

Table 2.1: Number of days with different ranges of rainfall, 1996-2000															
Range (mm)	≥100	90-99.9	80-89.9	70-79.7	60-69.9	50-59.9	40-49.9	30-39.9	20-29.9	10-19.9	5-9.9	1-4.9	Total ≥1mm	<1	Total
1996	1	0	1	0	7	2	4	8	16	26	20	48	133	45	178
1997	0	0	2	1	2	3	3	7	10	29	32	47	136	54	190
1998	0	2	0	0	1	3	6	7	19	26	23	41	128	59	187
1999	2	0	0	0	3	2	8	11	7	25	25	46	129	54	183
2000	1	0	1	0	5	2	3	7	15	29	28	34	125	59	184

Table 2.2: Number of hours with different hourly rainfall range, 1996-2000								
Range (mm)	40.0-49.9	30.0-39.9	20.0-29.9	10.0-19.9	5.0-9.9	1.0-4.9	<1.0	Total
1996	1	4	4	42	81	322	430	884
1997	0	1	4	32	76	315	429	857
1998	1	0	5	36	71	325	491	929
1999	0	1	4	29	100	341	480	955
2000*	0	4	4	24	55	230	373	690*

* Values affected by problems with the data logger

Table 2.3: Five largest daily rainfall events & total annual rainfall, 1996-2000 (mm)						
	1st	2nd	3rd	4th	5th	Total annual rainfall
1996	125.8	85.0	66.1	64.7	63.0	2245
1997	89.2	87.9	76.9	69.7	63.9	1938
1998	97.1	93.2	68.1	57.2	53.7	2049
1999	112.8	108.0	65.8	62.0	61.0	2078
2000	109.8	84.8	65.8	64.2	60.4	2118
Variation (%)	41	27	17	12	19	2086

89.2 to 125.8 mm. In other words the inter-year variability of annual rainfall was moderate (16%) but the variability of highest rainfall in a day was high (41%). The maximum hourly rainfall rate also showed a high inter-year variability of 45% over four years (45.6 mm in 1996, 34.6 mm in 1997, 49.0 mm in 1998, 33.8 mm in 1999) (Table 2.2). In the different years, 78-85% of the days with rain had a rainfall of less than 20 mm, and around 51-55% had a rainfall of less than 5 mm (Table

2.1). There were between 3 and 9 days in each year with a high rainfall of more than 60 mm.

Around half of the hours with rain (49-53%) had a rainfall of less than 1 mm, and about 85-88% had a rainfall of less than 5 mm (Tables 2.2 and 2.4). Less than 5% of the hours with rain had a rainfall of more than 10 mm (likely to cause soil erosion).

Table 2.4: Proportion of rainy hours with different amounts of rain (%)

	>10 mm	>5 mm	<5 mm	<1 mm
1996	5.8	14.9	85.1	48.6
1997	4.3	13.2	86.8	50.1
1998	4.5	12.2	87.8	52.9
1999	3.6	14.0	86.0	50.3

Runoff and soil loss

The total average runoff (m^3/ha) and soil loss (t/ha) for each treatment in each of the five years from 1996 to 2000 are shown in Table 2.5 (averages calculated from the three replicate plot values) together with the averages for the whole period.

Over the five-year period, the four hedgerow treatments showed reductions in runoff compared to the control plot (T1), farmers' practice) of 38% (T2), 13% (T3), 33% (T4), and 37% (T5) (Table 2.5). The reduction in runoff increased with time for all treatments except T3 in 1999 and 2000, with runoff from T2, T4, and T5 in the fifth year approaching or less than half that from the control plot.

The annual soil loss for the control plots and the treatment plots is also shown in Table 2.5. The average soil loss in individual years from the control plots ranged from 2.8 t/ha in 1996 to 131.6 t/ha in 1998; the average annual soil loss over the five-year period was 39.4 t/ha. The average annual soil loss from the treatment plots over the five years was only 11% (T2), 30% (T3), 17% (T4) and 11% (T5) of the control values. T3, without use of organic fertiliser, showed the greatest soil loss

Table 2.5: Summary of runoff and soil loss from 1996-2000

	Runoff (m^3/ha)					Soil loss (t/ha)				
	T1	T2	T3	T4	T5	T1	T2	T3	T4	T5
1996	802	604	757	641	644	2.8	0.4	1.5	0.7	0.6
Percent of T1		75	94	80	80		15	55	24	23
1997	495	361	426	380	367	3.9	0.2	0.9	0.4	0.2
Percent of T1		73	86	77	74		5	22	10	5
1998	1,401	876	1,075	924	833	131.6	19.8	46.8	29.8	20.5
Percent of T1		63	77	66	59		15	36	23	16
1999	643	341	547	376	375	8.3	0.0	1.0	0.1	0.2
Percent of T1		53	85	58	58		1	12	1	2
2000	873	419	870	501	445	50.5	1.4	8.7	2.4	1.1
Percent of T1		48	100	57	51		3	17	5	2
Average	843	520	735	564	533	39.4	4.4	11.8	6.7	4.5
Percent of T1		62	87	67	63		11	30	17	11

in each of the five years, mainly as a result of the extremely poor growth of crops with this treatment. The contour hedgerows of *Alnus nepalensis* (T2, T5) were slightly more effective than those of *Indigofera dosua* (T4) in reducing soil loss, largely because *Alnus nepalensis* grew better than *Indigofera dosua* under the local geoclimatic conditions.

The annual soil loss in 1998 was far greater than in all the other years, and those in 2000 somewhat greater than the other years apart from 1998. Soil losses were lowest in 1999 for all treatments except the control. Even in 1998, soil loss was considerably reduced in the treatment plots compared to farmer's practice (to between 19.8 and 46.8 t/ha, from 131.6 t/ha).

The monthly runoff and soil loss are shown in Tables 2.6 and 2.7 and the seasonal distribution of soil loss and runoff in Tables 2.8 and 2.9. The seasonal distribution of rainfall is shown in Table 2.10. In the two years when soil losses were high, 1998 and 2000, the greater part of the soil loss from the control plots (51 and 85%) occurred during the pre-monsoon period (April-May), even though only one-third of the runoff (37 and 29%) was observed during this period.

Table 2.6: Monthly runoff (m^3/ha) from 1996-2000

	1996					1997					1998				
	T1	T2	T3	T4	T5	T1	T2	T3	T4	T5	T1	T2	T3	T4	T5
Jan	23	25	23	23	23	4	3	3	3	2	-	-	-	-	-
Feb	7	6	5	7	5	-	-	-	-	-	8	7	7	7	7
Mar	13	12	13	16	10	3	2	2	2	2	43	24	25	27	26
Apr	0	0	0	0	0	25	15	16	18	16	242	203	201	199	223
May	6	0	4	0	0	40	19	21	22	23	234	211	246	245	176
Jun	183	129	142	137	128	126	83	84	80	80	151	70	100	74	68
Jul	203	148	181	163	139	176	139	151	150	144	475	200	254	207	171
Aug	210	160	199	166	176	99	86	132	87	84	205	132	198	132	132
Sep	146	114	179	118	153	-	-	-	-	-	30	18	34	20	19
Oct	11	10	11	11	10	-	-	-	-	-	10	9	8	9	9
Nov	0	0	0	0	0	-	-	-	-	-	3	3	3	3	3
Dec	0	0	0	0	0	23	16	17	17	16	-	-	-	-	-
Total	802	604	757	641	643	495	361	426	380	367	1,401	876	1,075	924	833

	1999					2000				
	T1	T2	T3	T4	T5	T1	T2	T3	T4	T5
Jan	-	-	-	-	-	-	-	-	-	-
Feb	-	-	-	-	-	-	-	-	-	-
Mar	-	-	-	-	-	10	8	7	9	7
Apr	2	2	3	3	2	188	70	97	106	64
May	101	28	60	31	48	58	22	50	28	22
Jun	150	97	123	105	99	315	96	213	103	103
Jul	313	156	293	174	168	44	27	65	30	29
Aug	40	23	34	28	24	203	152	334	177	168
Sep	-	-	-	-	-	54	45	103	47	51
Oct	37	34	34	35	34	-	-	-	-	-
Nov	-	-	-	-	-	-	-	-	-	-
Dec	-	-	-	-	-	-	-	-	-	-
Total	643	341	547	376	375	873	419	870	501	445

Table 2.7: Monthly soil loss (t/ha), 1996-2000

	1996					1997					1998				
	T1	T2	T3	T4	T5	T1	T2	T3	T4	T5	T1	T2	T3	T4	T5
Jan	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	-	-	-	-	-
Feb	0.01	0.00	0.00	0.00	0.01	-	-	-	-	-	0.00	0.00	0.00	0.00	0.00
Mar	0.13	0.03	0.05	0.08	0.03	0.01	0.00	0.00	0.00	0.00	2.47	0.02	0.03	0.03	0.03
Apr	-	-	-	-	-	0.11	0.01	0.01	0.02	0.01	37.75	16.86	23.85	15.80	15.09
May	0.01	-	0.02	-	-	1.43	0.02	0.05	0.14	0.03	26.44	2.69	19.97	13.90	5.30
Jun	1.94	0.15	0.40	0.32	0.16	0.70	0.04	0.07	0.04	0.04	23.75	0.14	0.81	0.04	0.01
Jul	0.46	0.11	0.71	0.14	0.11	1.51	0.10	0.46	0.14	0.06	40.81	0.03	1.60	0.03	0.02
Aug	0.18	0.10	0.22	0.08	0.15	0.07	0.03	0.26	0.02	0.03	0.30	-	0.43	0.00	-
Sep	0.06	0.02	0.13	0.03	0.17	-	-	-	-	-	0.04	-	0.07	-	-
Oct	0.01	0.01	0.01	0.01	0.00	-	-	-	-	-	0.01	0.01	-	0.01	0.00
Nov	-	-	-	-	-	-	-	-	-	-	0.01	-	0.01	-	-
Dec	-	-	-	-	-	0.04	0.00	0.02	0.00	0.00	-	-	-	-	-
Total	2.80	0.42	1.53	0.66	0.64	3.88	0.19	0.87	0.37	0.18	131.59	19.75	46.77	29.80	20.46

	1999					2000				
	T1	T2	T3	T4	T5	T1	T2	T3	T4	T5
Jan	-	-	-	-	-	-	-	-	-	-
Feb	-	-	-	-	-	-	-	-	-	-
Mar	-	-	-	-	-	0.03	0.00	0.01	0.01	0.01
Apr	0.01	0.00	0.00	0.01	0.00	42.65	0.86	1.56	2.09	0.44
May	3.25	0.03	0.28	0.09	0.09	0.59	0.00	0.49	0.01	0.00
Jun	1.33	0.01	0.04	0.01	0.03	6.87	0.27	4.08	0.10	0.07
Jul	3.72	-	0.63	0.00	0.03	0.02	0.01	0.27	0.00	0.00
Aug	0.00	-	-	-	-	0.21	0.14	1.45	0.13	0.42
Sep	-	-	-	-	-	0.07	0.07	0.86	0.03	0.11
Oct	0.02	0.00	0.00	0.01	0.00	-	-	-	-	-
Nov	-	-	-	-	-	-	-	-	-	-
Dec	-	-	-	-	-	-	-	-	-	-
Total	8.33	0.04	0.96	0.11	0.16	50.45	1.35	8.71	2.36	1.06

Table 2.8: Seasonal distribution of runoff in percent 1996-2000

	1996					1997					1998				
	T1	T2	T3	T4	T5	T1	T2	T3	T4	T5	T1	T2	T3	T4	T5
Premonsoon	2	2	2	3	-	14	10	9	11	11	37	50	44	51	51
Monsoon	93	91	93	91	94	81	85	86	83	84	62	48	55	47	47
Postmonsoon	1	2	1	2	2	-	-	-	-	-	1	1	1	1	1
Wintenr	4	5	4	5	4	5	5	5	5	5	1	1	1	1	1
Total	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

	1999					2000				
	T1	T2	T3	T4	T5	T1	T2	T3	T4	T5
Premonsoon	16	9	11	9	13	29	24	18	29	21
Monsoon	78	81	82	82	78	71	76	82	71	79
Postmonsoon	6	10	6	9	9	-	-	-	-	-
Wintenr	-	-	-	-	-	-	-	-	-	-
Total	100	100	100	100	100	100	100	100	100	100

Table 2.9: Seasonal distribution of soil loss in percent, 1996-2000

	1996					1997					1998				
	T1	T2	T3	T4	T5	T1	T2	T3	T4	T5	T1	T2	T3	T4	T5
Premonsoon	5	7	5	3	5	40	12	9	44	23	51	50	94	100	100
Monsoon	94	89	95	91	92	59	86	86	55	74	49	48	6	0	0
Postmonsoon	0	3	0	2	1	-	-	-	-	-	0	1	0	0	0
Winter	1	1	0	5	2	1	2	5	1	3	0	1	0	0	0
Total	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
	1999					2000									
	T1	T2	T3	T4	T5	T1	T2	T3	T4	T5					
Premonsoon	39	81	30	82	57	86	64	24	89	43					
Monsoon	61	12	70	12	43	14	36	76	11	57					
Postmonsoon	0	6	0	6	1	-	-	-	-	-					
Winter	-	-	-	-	-	-	-	-	-	-					
Total	100	100	100	100	100	100	100	100	100	100					

Table 2.10: Seasonal distribution of annual rainfall

	Pre-monsoon	Monsoon	Post-monsoon	Winter	Total
1996	3	89	3	5	100
1997	13	76	2	9	100
1998	19	77	3	1	100
1999	8	79	12	1	100
2000	17	81	1	1	100
Average	12	80	4	3	100

Discussion

Reduction of soil loss

The results show that all the hedgerow treatments considerably reduced soil loss from the second year of planting, and that the effect increased overall with time, and suggest strongly that contour hedgerows could be a useful tool to reduce soil loss from sloping agricultural land.

The pronounced effect of the contour hedgerows in reducing soil erosion results from a combination of factors. The hedgerows function as physical barriers to soil movement, and can function like a sieve to filter out sediment from surface runoff. They also decrease the velocity of the surface runoff by reducing the length of the slope through the formation of almost flat terraces separated by steep steps, thus reducing the amount of soil the water takes with it. At the same time, they reduce the total amount of runoff by slowing the water and allowing it time to penetrate the soil and by providing a thickly rooted area that can act as a sponge. Thus surface water runoff is slower, there is less of it, and it has a lower concentration of sediment, all of which mean markedly reduced soil erosion.

Runoff and soil loss from the Treatment 3 plots – hedgerows of *Alnus nepalensis* but without application of organic fertilisers – were higher than for the other three treatments although still lower than the control values. The main difference in the T3 plots was the very poor growth of crops. In all three replicates, the planted crops showed only moderate germination and growth in 1996, and very poor germination or growth from 1997 onwards. The vegetative cover in T3 was thus much lower than in the other plots. The reasons for this very poor growth are not entirely clear, but the results indicate that land cover per se is also very important for soil conservation. The T3 alleys were almost bare during the cropping season, but even then the soil loss was much less than from the control, which again illustrated that contour hedgerows can be very effective in reducing soil loss.

The soil loss from the control was actually very low in three of the five years studied, only around 3-8 t/ha, much lower than the generally accepted average level of 12 t/ha. In the other two years (1998 and 2000), however, it was very high – 131.6 and 50.5 t/ha – giving an average of nearly 40t/ha for the five years. This reflects the typical challenge for mountain agriculture: unpredictable downpour and cloudburst events that are localised and infrequent but can have a devastating impact when they occur.

Rainfall, runoff and soil loss

The annual variations in soil loss and runoff did not correlate with total annual rainfall. For example, although 1998 had by far the highest values for runoff and soil loss, the annual rainfall in this year was the second lowest.

Soil loss did appear to be associated with intense rainfall events, but only at certain times of year. Much of the massive soil loss in 1998 was caused by a single rainfall event of 49 mm/hour on 26 April and two premonsoon events of 18 and 20 mm/hr on 30 June and 1 May, although the control plots continued to lose soil thereafter, particularly in a series of events in July. Similarly most of the soil loss in 2000 was caused by several rainfall events ranging from 4.2 to 12.8 mm/hour during late April. However, a rainfall event with 45.6 mm/hour on 10 September 1996 did not cause much soil loss, and although over the five years there were many rainfall events with an intensity of more than 20 mm/hour during the monsoon period, soil loss from these was extremely low compared with the soil loss caused by events of only 4.2-12.8 mm/hour in April 2000. The main reason for this difference is probably the difference in land cover. The land was almost bare in the pre-monsoon shortly after planting maize (March 1998 and April 2000) and very susceptible to erosion as the plants were not fully established, but there was good crop cover during the monsoon.

The total runoff also tended to be higher for rainfall that fell during the premonsoon season. For example, although only 19% of the rainfall fell in the premonsoon season in 1998 it caused 37-51% of the annual runoff (depending on the treatment), whereas the 77% of rain that fell in the monsoon season caused only 47-62% of the annual runoff. In the years when there were fewer premonsoon rainfall events (1996, 1997, 1999), the monthly runoff and soil loss were more closely related to the monthly rainfall pattern.

The results suggest that the pre-monsoon period, especially April, is a very critical season for soil conservation of sloping agricultural land in the mid hills. At this time one or two critical rainfall events can cause a large proportion of the annual soil loss, and higher losses altogether than in years where a plot is not affected by heavy rain during this period. This confirmed the findings of Carver and Nakarmi (1995) who observed two critical events to produce 50-90% of annual total soil loss from sloping land.

Vegetation cover and soil loss

The results of this study, in which higher soil losses were observed from the plot with poor crop development and from bare land in the pre-monsoon, confirm the common belief that land surface cover plays a very important role in soil conservation. Maintaining sufficient surface cover is important for the reduction of soil erosion.

Contribution of largest erosion events to annual soil loss

The total number of soil erosion events varied from 34 in 1999 to 60 in 1996 with around 40 in 1997, 1998, and 2000. Of these events, the five largest contributed between 75 and 90% of the total annual soil loss in the different treatment plots; and the largest 10 events contributed between 90 and 100% of total annual soil loss. This confirms the observations by Nakarmi et al. (2000) that around ten events generated 90% of annual soil losses from a rainfed agricultural terrace. This has important implications for erosion research and mitigation. Data collection for plot-based soil erosion research is a resource intensive activity. In the experiments described here, at least four persons had to work full time on data collection for the fifteen soil erosion plots during the monsoon season. If a way can be discovered of capturing the most important 5 to 10 erosion events, and ignoring the other 30 or more, then it may be possible to perform such research, and investigate mitigation approaches, much more effectively.

Conclusions

The reported rates of soil loss from sloping agricultural under farmers' practice (similar to the control used in the trials) vary greatly, from 1 to 120 t/ha/year, but mostly seem to lie at around 20-60 t/ha/year (Partap and Watson 1994). In the present study, the average annual loss from the control plots was 39t/ha/year. These rates of soil loss have a marked negative impact on mountain agriculture. The results of this study, using hedgerows of *Alnus nepalensis* and *Indigofera dosua,* indicate that sloping agricultural land technology or SALT can greatly reduce soil loss from the second year of planting if the contour hedgerows are properly maintained. Properly managed, hedgerows can reduce soil loss by 80 to 99% from the fifth year on. The significant reduction in soil loss in the hedgerow plots was apparent both in terms of a substantial decrease in sediment concentration and in a reduced runoff velocity, which was the result of the hedgerows functioning as barricades. Total runoff was also reduced, although less markedly because of the high infiltration rate of the soils. These results suggest that SALT offers a potential alternative to traditional farming practices: using contour hedgerows, it should be possible to introduce continuous and sustainable cultivation of sloping land.

This study also demonstrated that SALT can be used in subtropical and temperate regions, not only in the tropical regions for which it was first developed. However, it is important to select appropriate hedgerow species (see Chapter 3). The species *Alnus nepalensis* used as the main demonstration species in these trials is not recommended as a hedgerow species for practical field applications because of the problems it poses when grown. The seeds are tiny and direct seeding is extremely difficult. Hedgerows can only be established by transplanting, and although successful, this technique is time consuming and resource intensive, and special care and techniques are needed to raise seedlings. Selection of appropriate hedgerow species is discussed in the fourth book in this series (Tang Ya 2004).

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Chapter 3

Changes in Soil Fertility of Sloping Agricultural Land with Contour Hedgerows of Nitrogen-fixing Plants

Tang Ya

Introduction

Soil fertility is one of the most important indicators of land productivity and one of the most important factors contributing to crop yield. Thus management of soil fertility is one of the most important issues in agricultural production; maintaining soil fertility for sustainable crop production is a great challenge.

Decline in soil fertility is a natural process that results from various factors. The main factor is growth and removal of crops without replacing the removed nutrients, particularly if crop residues are also removed. Soil fertility also declines as a result of nutrient loss through soil erosion and nutrient leaching, particularly on sloping land. In mountain areas, good arable cropland is becoming increasingly scarce as a result both of a decline in soil fertility and appropriation of arable land for other purposes. As the population increases, the number of marginal farms in the hills and mountains of the HKH is also increasing. Farms become smaller, and farmers start using land that was previously considered unsuitable for cropping. Much farming land in the HKH region is now on steep slopes; the lack of good arable land has become a crucial factor leading to food insecurity and poverty for most of the farming families in the region. Programmes on poverty reduction and livelihood improvement in the HKH region face great challenges. If a way can be found to stabilise and maintain the fertility of sloping agricultural land and other types of marginal land this could contribute considerably to livelihood improvement.

Management of sloping agricultural land for continuous cropping includes two basic components. One is effective control of soil erosion; the other is maintenance of soil fertility. The latter is particularly important from a farmer's point of view because it is directly related to crop yield. Sloping agricultural land often lies a considerable distance from a farmers' house, and ways need to be found to maintain soil fertility that don't require transport of large amounts of farm manure or other inputs.

Farmers have used numerous traditional methods to manage soil fertility, but in the past 2-3 decades application of chemical fertilisers has become the most important approach – and has contributed greatly to food security in many developing countries. Use of high yielding crop varieties combine with chemical fertilisers are the two most important factors contributing to producing food to meet the demands of the growing population. The amount of chemical fertilisers applied has increased drastically in the past decades. In India, for example, the amount of chemical fertiliser applied rose from 7,000 tonnes in the early 1950s to 13 million tonnes in 1998. Worldwide, the use of commercial fertilisers rose 10 fold between 1950 and 1995, and the use of pesticides rose 32 fold (Miller 1995). Agriculture today has become high-input agriculture. In the HKH region, chemical fertilisers became available rather later than elsewhere and the increase is more recent; the use of chemical N, P, and K in Nepal increased from 590 tonnes in 1964/1965 to 67,650 tonnes in 1998/1999 (Jha 2001), a rise of 114 times in 35 years.

Although the role of high yielding crop varieties (HYVs) and chemical fertilisers in enhancing crop yield has been well recognised worldwide, the negative impacts of this approach are also emerging. The negative impacts of HYVs include a decrease in the level of agrobiodiversity and the risk of losing many traditional land races, and catastrophic losses when a single variety is affected by disease or extreme climatic conditions. The main negative impacts of chemical fertilisers include soil acidification, soil compaction, decreased biological activity in the soil, and pollution of underground water. Some of these result from misapplication, especially unselective and excessive use, but these are difficult to prevent, and the negative impacts will increase if appropriate measures are not taken. Another problem is that for mountain farmers chemical fertilisers are often either too costly or not available at all. It is important to explore both traditional and new approaches to soil fertility management, especially in mountain areas, including application of farmyard manure, composting, green manure, and now use of hedgerows of nitrogen-fixing species.

Sloping agricultural land technology or contour hedgerow intercropping technology (SALT or CHIAT) has the potential to provide on-site production of mulch materials to improve soil fertility in addition to its other benefits. The method has proven effective in reducing soil erosion, improving soil fertility, and enhancing crop yield in subtropical China (Sun Hui et al. 1999a, 1999b, 2001, 2003; Tang Ya et al. 2001) as well as in many tropical areas. The following describes the results of the research experiment set up in 1993 at the ICIMOD Godavari Trial and Demonstration Site to assess the impact of hedgerows of nitrogen-fixing plants on soil fertility, specifically it describes the changes in soil fertility from 1995 to 2001.

Materials and Methods

Study site

The experiment was carried out in parallel with the study of the impact of hedgerows on soil conservation described in Chapter 2 and on the same treatment plots. The site and plots are described in Chapter 2.

The experimental site was on newly-cleared land in an area that had been degraded forest.

Experimental design

The experimental design was the same as in Chapter 2 and the study was carried out on the same monitoring plots used for the soil erosion study. Briefly there were five treatments each with three replicates: T1 the control was without hedgerows, and T2 to T5 were with hedgerows. Details of the plots and hedgerow treatments are provided in Chapter 2.

The alleys between the hedgerows were used for growing annual crops in treatments T2, T3, and T4, and peach and vegetables in T5. The same crop was planted for the same cropping season in T1, T2, T3, and T4; usually maize was planted in late March/early April followed by a dry season crop in late September/early October.

Except for T3, the locally available concentrated organic fertiliser 'kisan mal' (3% N, 5% P_2O_5 and 2% K_2O, see Chapter 2) was applied throughout the experiment at a rate of 16t/ha once per cropping season (twice a year) before planting for all treatments except T3. The hedgerows were pruned once in 1996 and twice a year from 1997 onwards. The fresh trimmings were weighed and spread as mulch in the alleys. The twigs were placed within the double hedgerows.

Sampling

Soil samples were collected once a year in March from a depth of 0-30 cm from 25 points at different positions in each T1 replicate control site and at 5 points at different positions in each of the 5 subplots in each T2 to T5 replicate site (i.e., 25 points within the site). The soil samples for an individual site were mixed thoroughly and a compound sample of 1 kg extracted. The samples were analysed separately and the values for each of the three replicates for a particular treatment averaged to provide a single value for the treatment.

Chemical analysis of soil samples

The soil samples were sent to outside laboratories for chemical analysis. The samples collected in 1995 and 1996 were analysed by the Soil Science Division, Nepal Agricultural Research Council; those collected in 1997 by Nepal Environmental and Scientific Services; and those collected in 1998-2001 by the Nanjing Institute of Soil Science, Chinese Academy of Sciences. The parameters measured included pH, organic matter, total nitrogen, available phosphorous, available potassium, and cation exchange capacity. From 1998 onwards, exchangeable calcium, exchangeable magnesium, exchangeable sodium, and exchangeable potassium were also added.

Biomass production of hedgerows

The hedgerows were pruned once in 1996 and twice a year from 1997 onwards. The annual total fresh biomass was recorded for each single row of the hedgerows.

Crop yield

The total crop yield was recorded for each plot.

Statistical analysis

The soil fertility data were analysed using the SPSS statistical analysis package.

RESULTS

The initial chemical properties of the soil are shown in Table 3.1 and the particle size in Table 3.2. More than 50% of the soil was silt and more than 25% clay, thus it can be classified as silty clay loam. Initially the soil had a high content of organic matter, moderate content of nitrogen, and low content of available potassium and phosphorous, and was very acidic. The initial values in the plots used for the different treatments were similar.

Table 3.1: Initial chemical properties of the soil

	pH	Total nitrogen (%)	Organic matter (%)	Available phosphorous (mg/kg)	Available potassium (mg/kg)
T1	4.3	0.29	7.87	7.27	271.3
T2	4.1	0.28	8.20	7.23	266.3
T3	4.3	0.28	8.33	6.87	205.0
T4	4.0	0.31	8.73	6.90	228.3
T5	4.1	0.27	8.40	7.07	222.7

Table 3.2: Percentage of soil particles of different size

	Particle size %						
	<0.002	0.05-0.002	0.1-0.05	0.25-0.1	0.5-0.25mm	1-0.5mm	2-1mm
T1	25.47	59.43	11.03	1.17	0.73	0.80	1.37
T2	27.83	53.17	14.93	1.13	0.63	0.87	1.43
T3	24.30	57.23	13.63	1.67	0.97	1.07	1.13
T4	26.53	56.20	11.83	2.33	1.03	1.03	1.03
T5	27.73	54.60	13.37	1.33	0.90	0.97	1.10

Changes in chemical fertility

Soil acidity

Soil pH value is an important indicator of soil fertility because it influences the availability of most of the nutrients required for plant growth. The most favourable pH values for nutrient release lie in the range 5.6-6.5. The pH value can also influence plant growth through its influence on toxic ions. When the pH value is below 5.0, aluminium, iron, and manganese may be soluble in sufficient quantities to be toxic to the growth of some plants. The average pH value of soil at the Godavari site is below 5; this is very acidic and indicates that there will be a limited availability of phosphates and some other nutrients as well as potential problems with toxic ions if these are present.

The average values of soil active acid (pH_{H_2O}) in the different treatment plots from 1995 to 2001 are shown in Figure 3.1. There was a slight increase in soil pH in all plots at the start of the experiment but the pH values remained below 5. It is difficult to change pH values except by applying lime.

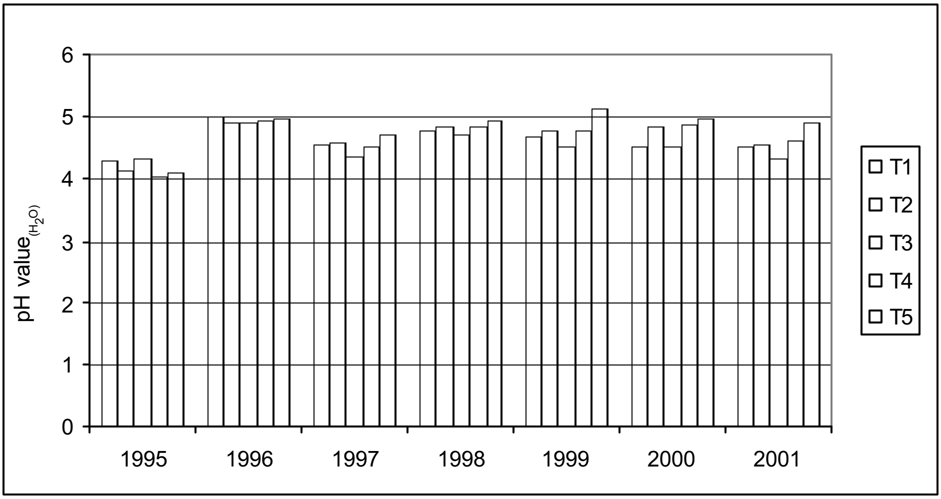

Figure 3.1: Soil active acid

At the start of the experiment, the highest pH value was in the T3 plots and the lowest in the T4 plots. After the experiment started, the T5 plot had the highest pH value in all years and the T3 plot the lowest. All treatments except T3 showed slightly higher pH values than the control plot T1 from 1997 onwards. The results indicate that intercropping with peach and vegetables (T5) can slightly improve soil acidity, that use of organic fertiliser can also help improve soil acidity, and that this improvement is greater if combined with digging in of hedge clippings. The slight improvement in pH value in all plots at the start of the experiment was not fully maintained in subsequent years, possibly as a result of leaching. Increasing the quantity of organic fertiliser might help to counteract this.

The values for soil potential acid (pH_{HCl}) are shown in Figure 3.2. The potential acid has shown a steady decrease in all treatment plots since it was first determined in 1998, indicating that the current type of land management can help improve this soil property.

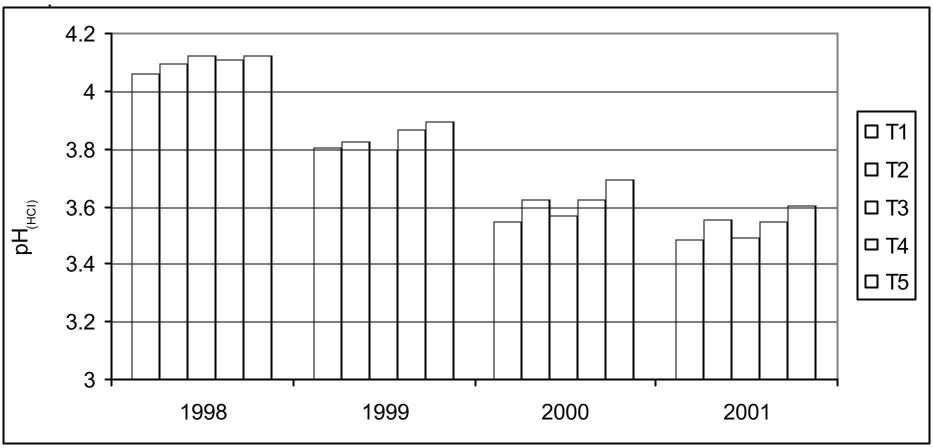

Figure 3.2: Soil potential acid

Soil organic matter

Soil organic matter functions as a 'granulator' of the mineral particles. Through its effect on the physical condition of the soil, organic matter increases the amount of water a soil can hold and the proportion of this water available for plant growth. Organic matter is also the main source of energy for soil microorganisms. The values of organic matter in the soils in the different treatment plots from 1995 to 2001 are shown in Figure 3.3.

As the soil at the test site had been a forest soil, the organic matter content was quite high (8-9%) when the experiment started. Agricultural soils elsewhere in the Kathmandu valley mostly have less than 2.5% organic matter (NARC 1997). The soil organic matter in the experimental plots declined fairly rapidly during the first two years and then remained at a more or less constant level of around 5% thereafter. It is possible that when soil organic matter is higher than 6%, it is more easily lost through various processes including decomposition and soil erosion.

Of all the treatments, soil organic matter was lowest in the control plots (no hedgerows) in 1995 and 1996 but highest in these plots from 1997 to 2001. The decline in organic matter content under the traditional farming system was apparently slower than under the treatments with hedgerows. The organic matter decreased by 26% between 1995 and 2001 in the control plots T1, but by around 45% in the plots with hedgerows. This was unexpected because hedgerows of nitrogen-fixing plants are generally regarded as an important source of soil organic matter.

There are three possible explanations. The first is the very low productivity of fresh biomass of *Alnus nepalensis* and *Indigofera dosua* during the experiment. Over the five years, the average annual fresh biomass was only 23.6-28.5 kg/plot for *Alnus nepalensis* and 9.8 kg/plot for *Indigofera dosua* (see below). The second explanation is a possible difference in nutrient loss through leaching. Nutrient losses through leaching are reportedly much higher than the losses to runoff and soil loss (Gardner et al. 2000). Runoff and soil loss were reduced considerably in the hedgerow plots T2, T3, T4 and T5 (Chapter 2), so there may have been more leaching in these plots,

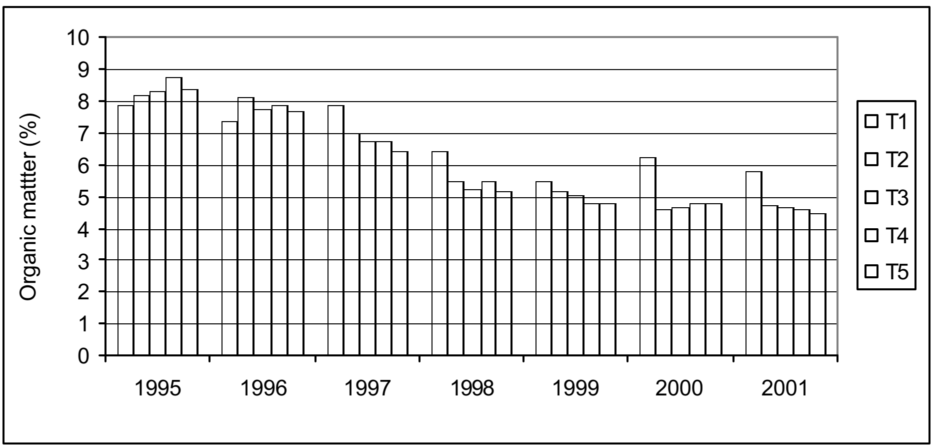

Figure 3.3: Soil organic matter

leading to more nutrient losses than in the control (T1). The third possible explanation is that as a result of damage by wildlife, the crops in the control were poorer than for the other treatments, except for treatment 3, so that there was less removal of nutrients by the crops.

The observed changes in soil organic matter are not fully compatible with the current understanding of fertility management of sloping agricultural land. It is generally expected that soil organic matter will decrease to quite a low level after several years of cultivation. However, continuous cultivation over seven years of quite steep sloping land without any soil conservation measures (T1) did not lead to the drastic decline in soil organic matter that was expected. Soil nutrient loss may be a longer process than is currently thought.

Total nitrogen

Soil nitrogen is one of the important elements of soil fertility and is often the contributing factor in the growth of many crops, and usually also the most limiting element in a soil. The soil nitrogen content in the different treatment plots from 1995-2001 is shown in Figure 3.4. There was an apparent large increase in the nitrogen content in 1996, which was most probably due to a laboratory error. With the exception of these probably erroneous results, there was a slow but constant decline in soil nitrogen which was more marked in the later years. From 1997 onwards, the control (T1) had the highest levels of nitrogen. The total nitrogen content in the five treatments declined by 12% (T1), 21% (T2), 25% (T3), 29% (T4), and 16% (T5), over the six years. As with organic matter, soil nitrogen declined more slowly in the control soil (T1) than in the treatments with hedgerows, indicating that hedgerows do not slow the decline in soil nitrogen. The probably causes for the slower decline in soil nitrogen in T1 are the same as those for organic matter.

Hedgerows of nitrogen-fixing plants have been advocated extensively for soil fertility improvement, especially soil nitrogen and soil organic matter. However, the present study did not support this. The different finding in this study could be because the

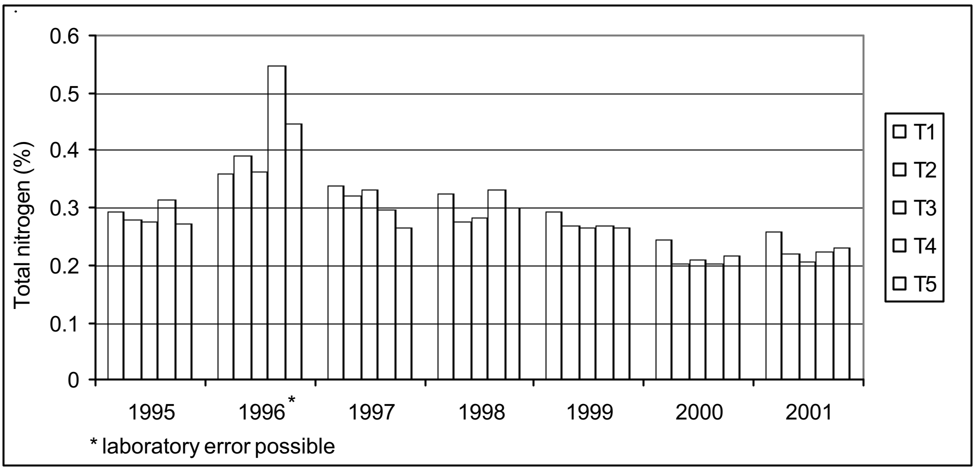

Figure 3.4: Soil total nitrogen

study was carried out on an already fertile forest soil, while other studies have been on agricultural lands cultivated for a long time or abandoned due to very low fertility. It would be useful to continue this monitoring of soil fertility to see how it changes in control and hedgerow treatments after 10, 15, and 20 years.

Available phosphorous

The soil content of available phosphorous in the different treatment plots from 1995 to 2001 is shown in Figure 3.5.

The amount of available phosphorous fluctuated considerably over the period of the experiment and showed marked variations between treatments. In 1996 the levels of available phosphorous were higher in all the experimental plots, including the control, than at the start of the experiment; in 2001 the levels were lower in all the plots except T5, and there were considerable variations in the intervening years. There were two interesting observations. From 1996 onwards, available phosphorous in the T3 plots, with no organic fertiliser, was consistently lower than for all other treatments; it decreased by 80% between 1995 and 2001 (6.87 to 1.39 ppm). The available phosphorous content in T5 was higher than at the start of the experiment in all years except 1998 and in 2000 and 2001 was considerably higher than in all other treatments.

A number of studies report that addition of organic residues to acidic soils can reduce Al toxicity and improve phosphorous availability (Haynes and Mokolobate 2001). However, in our tests incorporation of hedge clippings alone was not sufficient to maintain levels of available phosphorous. This was not unexpected as the biomass production of the hedgerows was quite low (see below). The combined use of commercial organic fertiliser (kisan mal) and hedgerow clippings is similar to the use of commercial organic matter alone, and did help maintain available phosphorous levels in most years. It seems that planting of peach trees may improve available phosphorous levels considerably, but the real reason for the high levels in T5 needs to be studied further.

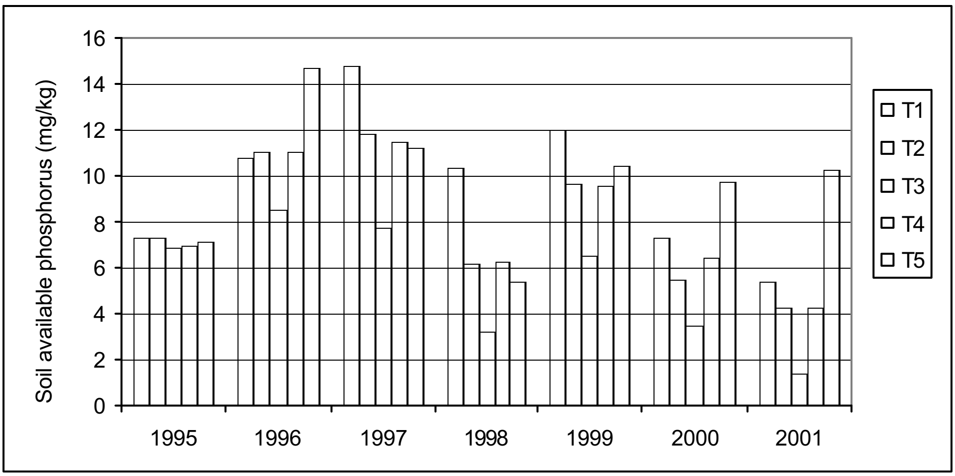

Figure 3.5: Soil available phosphorus

There was no correlation between the changes in available phosphorous and soil loss or runoff, indicating that the losses are not primarily through runoff and sediments.

Available potassium

The soil content of available potassium in the different treatment plots from 1995 to 2001 is shown in Figure 3.6.

The soil available potassium levels decreased rapidly at the start of the experiment reaching a stable level of less than half of the values at the start from 1998 onwards (the low value in 1997 was probably the result of a laboratory error). The pattern was similar to, but more marked than, that for soil organic matter. Similar results have also been observed in other parts of the middle hills of Nepal, potassium is one of the easiest nutrients to lose through leaching and soil loss.

Although the available potassium level in the control plot T1 was slightly higher than in the other plots at the start of the experiment, after 1999 it was consistently the lowest. This was probably because soil loss was much higher from this plot. The second lowest values were observed in the T3 plot, which also had the next highest values of soil loss. In contrast, although the available potassium level in the T5 plots was the second lowest when the study started, from 1998 onwards it was consistently the highest – although only by a small margin.

The amount of available potassium lost in sediments is probably quite high. The results indicate that hedgerows can help slow down the loss of available potassium, mainly through reducing soil erosion. It seems that, as with available phosphorous, the actual land management practice can also affect available potassium; further study is needed on this. Since potassium is easily lost, it might be necessary to use a potassium fertiliser to compensate for the loss of potassium from the soil.

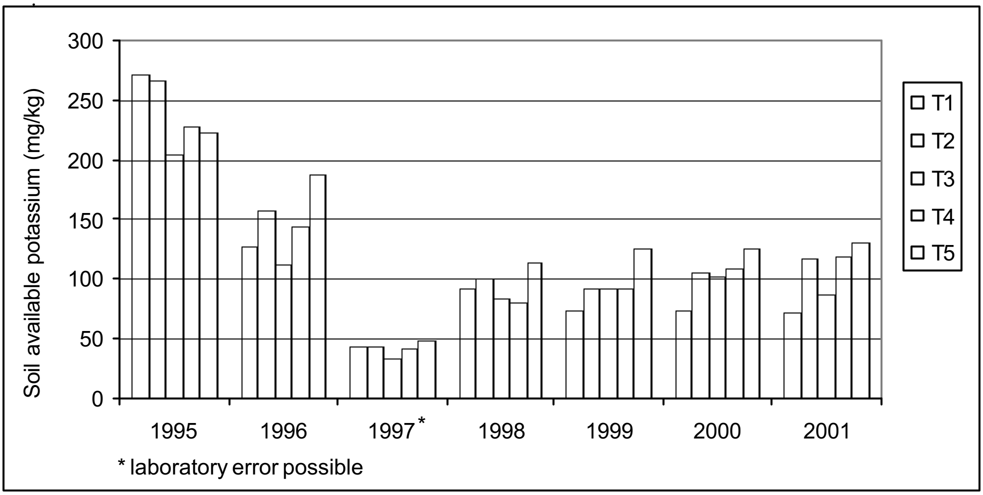

Figure 3.6: Soil available potassium

Effective cation exchange capacity (ECEC)

The effective cation exchange capacity (ECEC) in the different treatment plots from 1998 to 2001 is shown in Figure 3.7. Since the soil was acidic, the effective cation exchange capacity (ECEC) was measured in place of the cation exchange capacity (CEC).

CEC is an important chemical property of soil; it is usually related to soil fertility and to the capacity of a soil to resist nutrient leaching. Soils with low CEC are more subject to leaching.

The ECEC levels remained fairly constant in all plots from 1998 to 2000, followed by a small increase in 2001, which was more marked in the T3 than the other plots. The hedgerow treatments appeared to have no effect on the ECEC: the values in the T1 control plots were similar to those in the other plots.

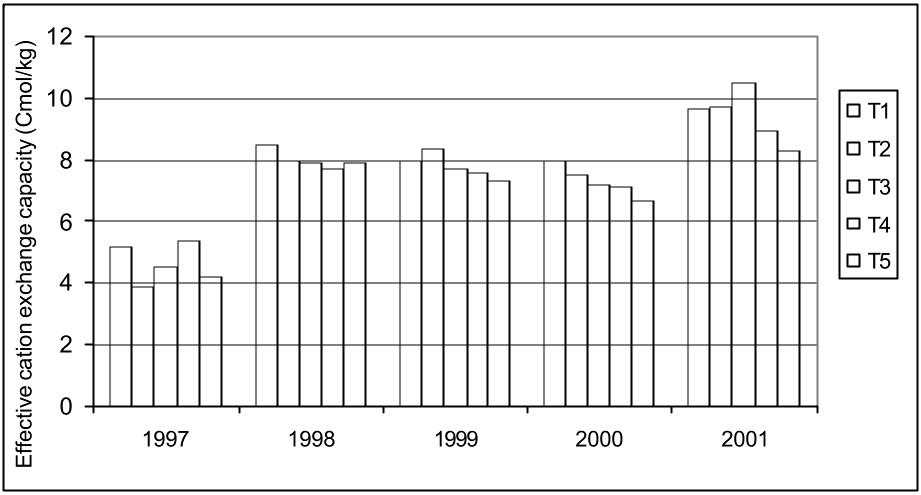

Figure 3.7: Soil effective cation exchange capacity (CEC)

Exchangeable calcium

The soil content of exchangeable calcium in the different treatment plots from 1998 to 2001 is shown in Figure 3.8.

The values fluctuated slightly in all plots for the first three years and increased markedly in 2001. The values were lowest in T3, without organic fertiliser in all years except 2001, and second lowest in the T1 control plot. These findings were consistent with the measurements of pH_{H_2O}: from 1998-2000 although there were only minor differences in pH value among treatments, the T3 value was consistently the and the T5 value the highest.

The results indicate that application of organic fertiliser can help maintain levels of exchangeable calcium.

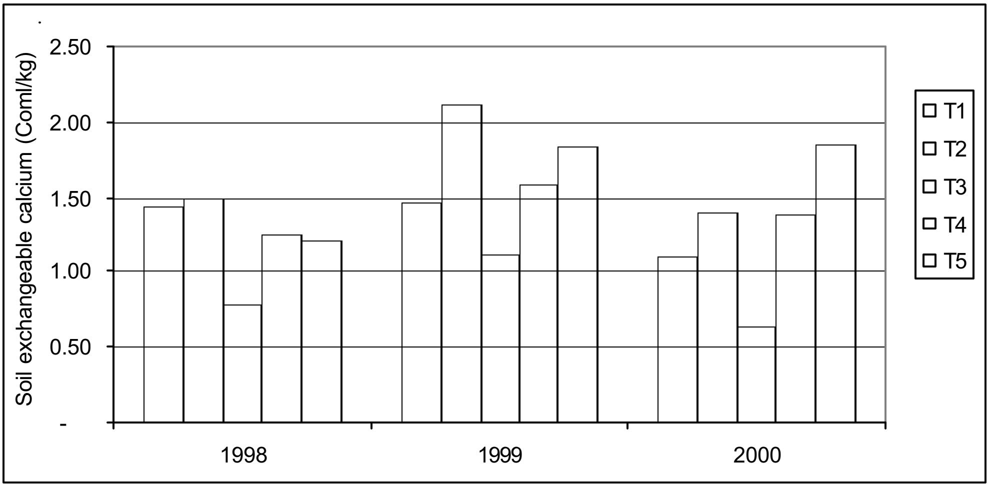

Figure 3.8: Soil exchangeable calcium

Exchangeable magnesium

The soil content of exchangeable magnesium in the different treatment plots from 1998 to 2001 is shown in Figure 3.9.

With the exception of T3, the values of exchangeable magnesium showed a slow but constant increase under all treatments over the four years. In all years, it was lowest in the T3 plots and highest in the T5 plots, although by 2001 the levels in the T2 and T4 plots were approaching those under T5.

The results suggest that organic fertiliser improves the availability of exchangeable magnesium and that this effect is more marked when it is used in combination with hedgerows. Furthermore, specific types of land use management (planting peach trees) may also improve the availability of exchangeable magnesium.

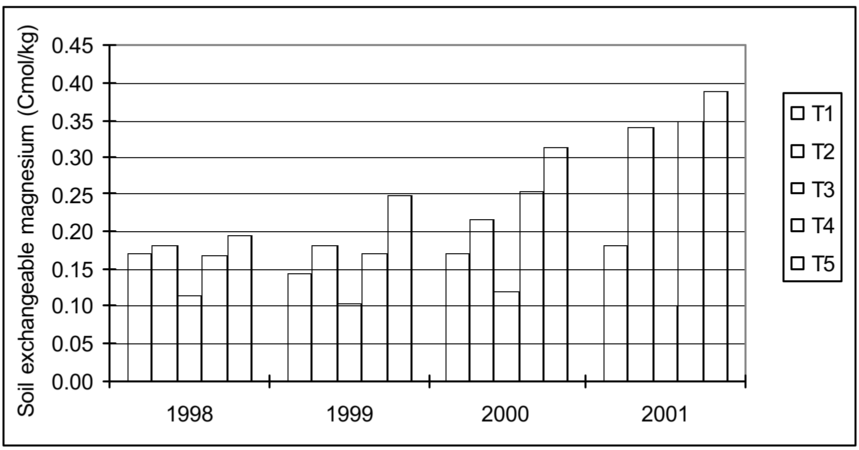

Figure 3.9: Soil exchangeable magnesium

Exchangeable sodium

The soil content of exchangeable sodium in the different treatment plots from 1998 to 2001 is shown in Figure 3.10. There was a considerable fluctuation in the levels of exchangeable sodium both between years and between treatments, with generally higher values in 2001 than in 1998 for all treatments except T5. There was no obvious effect of hedgerows, organic fertiliser, or land use.

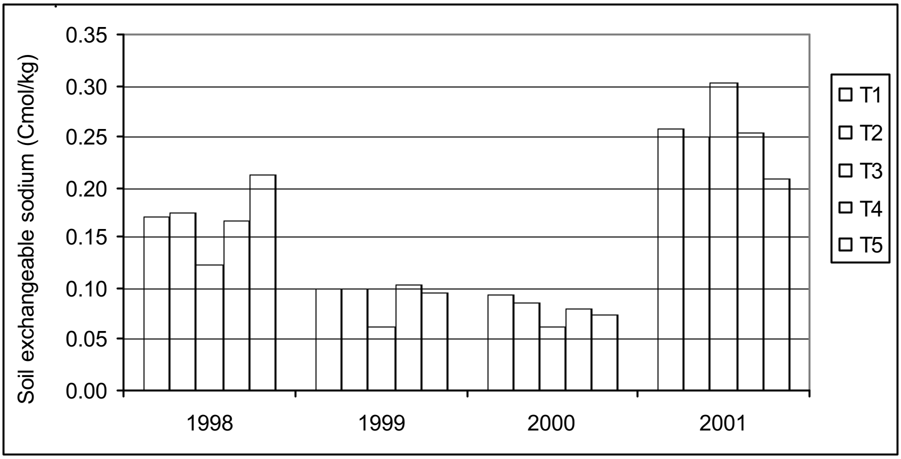

Figure 3.10: Soil exchangeable sodium

Exchangeable potassium

The soil content of exchangeable potassium in the different treatment plots from 1998 to 2001 is shown in Figure 3.11. With the exception of 2000, the values of exchangeable potassium showed a slow but constant increase under all treatments over the four years, indicating an improvement in soil quality. In all years, it was lowest in the T1 (control) plots and highest in the T5 plots, although by 2001 the levels in the T2 and T4 plots were approaching those under T5.

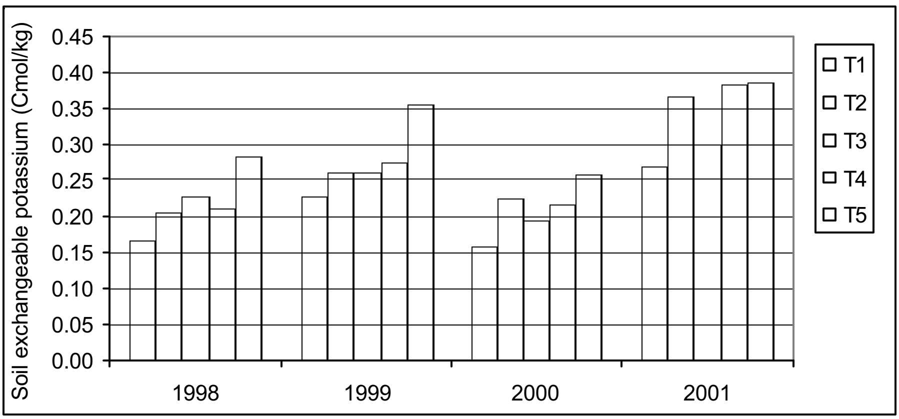

Figure 3.11: Soil exchangeable potassium

The results suggest that hedgerows improve the availability of exchangeable potassium and that this effect is more marked when hedgerows are used in combination with organic fertiliser. Furthermore, specific types of land use management (planting peach trees) may also improve the availability of exchangeable potassium, although this requires further study.

Biomass production of hedgerows

One of the important benefits of SALT is the availability of fresh biomass from the hedgerows which can be used to improve soil fertility. The biomass production of the hedgerows will determine to some extent the effectiveness of soil fertility improvement and one of the important criteria in the selection of suitable hedgerow species is the production of biomass. However, at present little information is available on suitable hedgerow species for subtropical to temperate regions. This is discussed further in another volume in this series (Tang Ya and Thapa 2004).

The biomass production of the hedgerow species used in the soil erosion plots was measured from 1996 to 2001. The hedgerows were established in late June 1995 and first pruned in 1996. They were pruned twice in each of the following years except 2000 when they were pruned once. The total biomass produced by each row of hedgerow plants (eight rows of 5m in double hedgerows and one row of 5m in a single hedgerow) in each plot was measured. The combined production in each of the years 1996 to 2001 of the four upper rows in each of the double hedgerows (UR), of the four lower rows in each of the double hedgerows (LR), and of the single lowermost hedgerow (SR) were calculated and the average over the three replicates determined. The results are shown in Table 3.3 together with the total average production per plot in each year and the average annual production from 1996 to 2001.

Table 3.3: Fresh biomass production of hedgerows of soil erosion plots (kg)

	Hedgerow	1996	1997	1998	1999	2000	2001	Average
T2	UR	3.60	23.50	3.10	13.00	14.67	17.27	12.52
	LR	3.40	21.83	3.07	12.57	13.83	14.23	11.49
	SR	3.37	9.13	0.20	3.30	6.17	4.87	4.51
	Total	10.37	54.47	6.37	28.87	34.67	36.37	28.52
T3	UR	2.30	17.37	1.63	12.10	16.67	20.03	11.68
	LR	2.27	14.20	1.17	10.83	18.33	17.63	10.74
	SR	3.50	5.90	0.30	3.80	6.67	6.40	4.43
	Total	8.07	37.47	3.10	26.73	41.67	44.07	26.85
T4	UR	3.80	4.87	2.93	4.90	3.33	7.70	4.59
	LR	3.47	4.07	2.23	4.23	2.83	4.00	3.47
	SR	3.80	1.77	0.23	0.90	1.00	2.60	1.72
	Total	11.07	10.70	5.40	10.03	7.17	14.30	9.78
T5	UR	4.07	25.37	3.58	10.77	8.83	10.67	10.55
	LR	3.83	22.27	2.47	9.93	8.33	7.47	9.05
	SR	3.10	7.90	0.87	2.97	4.33	4.77	3.99
	Total	11.13	55.53	6.91	23.67	21.50	22.90	23.61

UR = sum of production from all upper rows of the double hedgerows (total length 20m); LR = sum of production from all lower rows of the double hedgerows (total length 20m); SR = production of single row at base of plot (total length 5m). The values are the average of three replicates for each treatment.

The average biomass production of *Alnus nepalensis* was similar for the different treatments, although in the last two years it was clearly less in T5 than in T2 and T3 – presumably because of increased shading by the peach trees. The biomass production of *Indigofera dosua* (T4) was much lower, only 37% of the average production of *Alnus nepalensis* in T2, T3, and T5. The average fresh biomass production of *Alnus nepalensis* over the 6 years was 26 kg/plot (24 to 29 kg in the different plots), equivalent to 59 kg/100m or 2.6 t/ha. Biomass production was lowest in 1998, especially for *Alnus nepalensis*, consistent with the marked dieback in that year which was probably due to climatic factors (cold and storm, see Tang Ya and Thapa 2004). The biomass production in the last two years of the experiment was more or less constant for all the treatments, indicating that 'steady state' production from mature hedgerows of *Alnus nepalensis* under normal climatic conditions is close to 90 kg/100m or 4 t/ha.

In all treatments and years, the upper row of the double hedgerows produced slightly more fresh biomass than the lower rows. This is probably because the upper rows are the first barrier encountered by runoff from higher up the slope, and more soil is deposited on the upper rows than on the lower rows. The difference was not significant, however. Production under T3 was no less than for T2 and T5, suggesting that the soil nutrient loss from soil erosion of the whole plot does not affect hedgerow growth negatively.

Crop yield

Table 3.4 shows the crop yield for the different treatment plots from 1995 to 2001. Crop yield is a good indicator of soil fertility. However, the experimental plots were located in a forest area with no other cropland nearby and it was very difficult to

Table 3.4: Crop yield from the soil erosion plots (average of three replicate plots) (kg/plot)

Year	Crop	Yield				
		T1	T2	T3	T4	T5*
1995	Millet	17.0	17.2	12.3	15.3	
1996	Maize	16.1	14.6	2.4	16.4	
	Millet	8.1	6.3	3.2	5.7	
	Soybean					1.5
1997	Maize	15.7	15.3	2.4	16.4	
	Soybean	2.0	1.0	0	0	
	Bush Bean					0
1998	Maize	4.8	7.0	0	7.2	
	Soybean	1.1	1.1	0	1.9	3.4
	Mustard	0.2	0.3	0	0.3	
	Radish					28.7
1999	Maize	0.3	0.7	0.1	0.6	0
2000	Maize	0	0.5	0	0.9	
	Soybean	0	0.1	0	0.1	
2001	Maize	0.6	0.7	0	0.8	
	Mustard	0.1	0.1	0	0.1	
	Radish					30

*The T5 plots also produced a harvest of peaches from 1998 onwards protect the crops from wildlife. Damage of crops by wildlife was common and the crop yield data are a very poor indicator of actual soil fertility. Nevertheless, they provide some indication of the differences in the different treatment plots.

The one clear finding is that the yield from the T3 plots, with no organic fertiliser treatment, was consistently much lower than the yield from T1, T2, and T4, and that the difference increased with time – from some 30% lower in 1995 to 50 to 80% lower in 1996. After 1997, there was barely any yield from the crops planted in T3.

Discussion

Hedgerow intercropping systems have several potential benefits including reduction of soil erosion, discussed in Chapter 2, and improvement of soil fertility, which is the subject of this chapter. One of the main components of soil fertility management is the maintenance of adequate levels of soil organic matter. This requires the input of crop residues and organic fertilisers to the soils in sufficient quantities to compensate for the rapid decomposition of organic matter. Improvement of soil fertility is generally considered to be one of the significant advantages of the SALT (CHIAT) or hedgerow intercropping system as the hedgerows have the potential to produce large amounts of organic material on site (the clippings) that can be cut and incorporated into the soil as mulch or green manure. Periodic additions of large amounts of organic material are known to have a favourable effect on soil physical and chemical properties.

There are a number of reports describing the effects of different hedgerow species on soil fertility (for example Yamoah et al. 1986; Hauser and Kang 1992). Lal (1989) and Kang and Ghuman (1991) showed that alley cropped plots had higher soil organic matter, extractable P, and exchangeable cations than control plots. Many other studies have shown that hedgerows of nitrogen-fixing plants can improve soil fertility (for example Sun Hui et al. 1999, 2003). Almost all of these studies were carried out on cultivated agricultural soils, and most were in tropical areas.

In contrast to such reports, at the Godavari site the hedgerows had little effect on soil fertility parameters like organic matter and nitrogen. There were probably two main reasons for this. One is that the soil at the site had been a forest soil and already had higher contents of most nutrients at the start of the trials than most agricultural soils. The second is that the biomass production of the two hedgerow species used in this study was rather low. The average biomass production of the *Alnus nepalensis* hedgerows over the six years of the study was less than 3 t/ha, and that of *Indigofera dosua* was less than half of this. In contrast, some widely used hedgerow species, such as *Leucaena leucocephala* can produce as much as 7.4 t/ha year as hedges in tropical Africa (Kang 1993). But high production is not limited to tropical areas: the annual fresh biomass production of *Leucaena leucocephala* planted as hedgerows in subtropical China was reported to be 8-14 t/ha, or 3.2-5.6 t/ha of dry matter (Sun Hui et al. 2003). It is also not clear why there was little difference in the soil fertility parameters of the plots with *Alnus nepalensis* hedgerows and those with *Indigofera dosua* hedgerows, given that nearly three times as much biomass was added to the former.

Hedgerows not only have the potential to improve soil fertility through production and incorporation of organic matter, by choosing species that are nitrogen-fixing, they should be able to directly increase the levels of soil nitrogen from their roots and through incorporation in the soil of the leaves. However, in these trials the input of nitrogen from the hedgerow clippings of *Alnus nepalensis* and *Indigofera dosua* was very low. The content of N in fresh young leaves of *Alnus nepalensis* is low, 2.6% (Sharma et al. 1994) compared to 4.3% for *Leucaena leucocephala* leaves, for example (NAS 1977). Thus the average annual N input from hedgerow clippings was only 0.15-0.19 kg/plot, or 15-19 kg/ha. The contribution of hedgerow clippings in terms of both organic matter and nitrogen was far below the amount needed to maintain soil fertility.

One type of land use management, planting of peach trees in the alleys with intercropping of vegetables (Treatment 5), did increase the availability of several nutrients, especially available phosphorous and potassium. This phenomenon needs to be studied further. Possible explanations could include the effect of the root systems, or of chemical compounds from the peach plants including materials secreted from the roots and decomposed leaves. The T5 plots contrasted strongly with the plots that did not receive organic fertiliser (Treatment 3). The growth of crops in these plots was extremely poor and as a result, removal of nutrients through crop yield and residues was very low compared to T5, where there was a good harvest of vegetables and peaches, nevertheless the soil fertility factors in T5 were better than those in T3. A further study would be useful to explore the differences and their cause.

Sanchez (1995) compared the results of many long-term experiments in which crops and trees were grown simultaneously and concluded that alley cropping (hedgerow intercropping) was most likely to be successful on fertile soils with reliable and adequate rainfall. The present study and those of Sun Hui et al. (1999a,b; 2003) in Ningnan, China, suggest that the conditions under which hedgerow intercropping can be successful are wider, and also less straightforward. Contour hedgerow intercropping was successful in Ningnan despite conditions of very poor soil and a long drought season; it was less successful at the Godavari site even though the biophysical conditions and soil fertility at the site were much better than those at Ningnan.

Conclusions

The results of six years of monitoring of soil fertility changes in the soil of different treatment plots with use of hedgerows and farmer's practice (as control) show that the contour hedgerows of *Alnus nepalensis* and *Indigofera dosua* could not maintain soil fertility, especially in terms of soil organic matter and nitrogen. This was partly because the initial values of both nitrogen and organic matter were high, but was also the result of the very low biomass production of both hedgerow species.

Essentially in these trials the hedgerows proved effective in combating the major problem of farming sloping land – soil erosion – but were much less effective in maintaining soil fertility. However, since this study started with a fertile forest soil, rather than a degraded agricultural soil, the impact of the hedgerows over a longer time interval may show different results. As a result of the much more serious soil loss from the control plots, it is expected that these plots will show a higher loss of soil nutrients in the future. The contour hedgerows of nitrogen-fixing plants may be seen to have a more marked beneficial impact on soil nutrients in the long term.

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Chapter 4

Nutrient Competition Between Hedgerows and Crops in a Contour Hedgerow Intercropping System

Tang Ya

INTRODUCTION

Sloping agricultural land technology (SALT), or contour hedgerow intercropping agroforestry technology (CHIAT) as it is often called, has been promoted in the HKH region since the early 1990s. However, during the course of testing, demonstration, and extension, a number of concerns have appeared. A particular concern voiced by farmers is that of competition between the hedgerows and crops for nutrients; this is a major consideration for farmers when deciding whether to adopt the technology.

Nutrient competition

Plants require light, nutrients, water, and soil for their growth and survival. The incorporation of woody perennial plants as hedgerows into a cropping system on sloping land introduces the possibility of competition between the hedgerow plants and crops in the alleys for light, nutrients, and water. Competition between hedgerow plants and companion crops is probably the most frequent reason given as to why crops have not yielded more under hedgerow intercropping than when grown alone (Lal 1989; Singh et al. 1989; Fernandes et al. 1990).

The competition between hedgerows and crops can be both above and below ground. Competition for light is the most prominent above-ground factor. This can be reduced by timely pruning, as confirmed by some authors. For example, Leihner et al. (1996) showed that there was no decisive shading effect on crops when hedges were pruned 2-3 times a year. The below-ground competition includes competition for nutrients and competition for soil moisture. The competition between a hedgerow and crops for nutrients might be very severe as both the hedgerow and the crop species have a tendency to concentrate their roots in the fertile surface soil. Kang (1993) cites a number of studies conducted in various parts of the tropics with different hedgerow species that showed significant reductions in performance and yield when crops were grown in the first few rows adjacent to the hedgerows (*Inga edulis*, Fernandes et al. 1990; *Senna spectabilis,* Basri et al. 1990; *Calliandra calothyrsus* and *Paraserianthes falcataria*, Evensen and Yost 1990).

Research, testing, and demonstration of contour hedgerow intercropping in the HKH region started in 1991 but there have been few studies on hedgerow-crop competition, although there have been reports of a considerable increase in soil nitrogen and organic matter in a system established on very poor soil in Ningnan, China (Sun Hui et al. 1999). The results from ICIMOD's project on Appropriate Technologies for Soil Conserving Farming Systems (ATSCFS) in six of ICIMOD's member countries also indicated the positive effects of contour hedgerows of nitrogen-fixing plants on soil fertility. Furthermore, there is increasing evidence that alley cropping has the potential to improve soil conditions, particularly nutrient availability (Lal 1989; Yamoah et al. 1986) and soil physical structure. Although competition for nutrients was identified as one of the highest priorities for research (Anderson et al. 1993), it has not yet been thoroughly investigated (Gregory 1996). The following describes the results of an experiment carried out between 1998 and 2001 at ICIMOD's Godavari Trial and Demonstration Site in the mid hills of Nepal to investigate the competition between hedgerow plants and crops for soil nutrients in a SALT system.

Materials and Methods

Study site

The experiment was carried out at ICIMOD's Godavari Trial and Demonstration Site. The site characteristics are summarised briefly in Chapter 1.

The experiment was carried out along a single established hedgerow alley. The hedgerows of *Alnus nepalensis* had been established in 1993 with seedlings. In 1998, when the experiment commenced, the alley between the two hedgerows had already become a level terrace; the riser at the upper side was about 70 cm high. Vegetables or maize had been planted along the alley for about four years prior to the study.

Experimental design

The experiment consisted of two treatments with three replicates. Treatment 1 was with cultivation of crops and Treatment 2 without crops (control). The basic layout is shown in Figure 4.1**.** The two treatments were arranged alternately along one alley with about 1m gap between treatments as a buffer area. The alley was around 5m wide; experimental plots 5m long and 3m wide were laid out close to the terrace hedgerow, i.e., there was a gap of 1.5m or more between the study plot and the terrace riser at the upper side.

The crops in Treatment 1 were planted according to normal farmer's practice in the area. Radish was planted in October and harvested in March/April of the following year, maize was planted in March/April and harvested in late September or early October of the same year. The first crop was radish planted in 1998, the last crop was radish planted in 2000. Four rows of crops were planted in each plot (Figure 4.1). Local varieties of both maize and radish were used. A locally purchased concentrated organic fertiliser 'kisan mal' (see Chapter 2) was applied to the treatment plots with crops at a rate of 16 t/ha for each planting season; its nutrient composition is 3% N, 5% P_2O_5, and 2% K_2O.

Crop yield was measured row by row. The weight of corn seeds and total biomass were measured for maize; the fresh weight of the radish root was measured for radish.

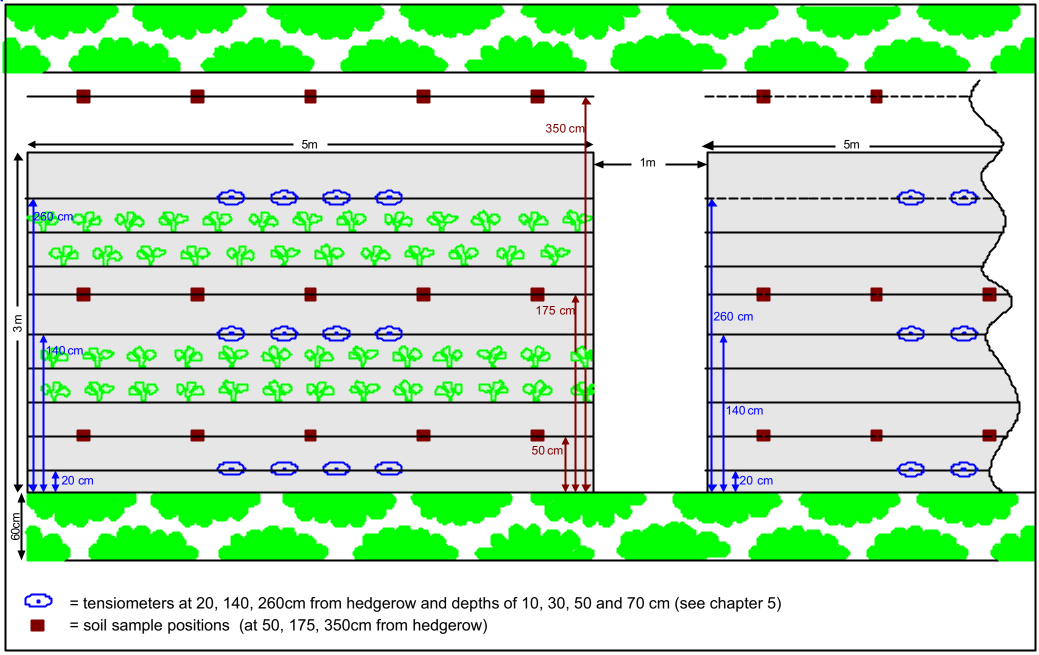

Figure 4.1: Experimental layout

The fresh biomass produced each year by the two rows of the double hedgerow bounding the alley was also measured.

Soil samples were collected in 1999, 2000, and 2001 from a depth of 0-30 cm at distances of 50, 175, and 350 cm from the hedgerow of the alley. The samples were collected in March or April after radish was harvested and just before the maize was sown. Soil samples were collected at five points within each experimental plot at each distance and were mixed to obtain one compound sample for each distance for each treatment. A representative 1 kg sample was taken from the compound sample. The soil samples were analysed at the Nanjing Institute of Soil Science, Chinese Academy of Sciences.

The experiment was repeated three times in consecutive years from 1998 to 2001. The first crops were planted in 1998 and the first soil samples taken in 1999 before the second maize crop was planted.

Results

Soil fertility

Soil acidity (pH value)

The values for soil active acid (pH_{H_2O}) for each of the three distances from the hedgerow in the two treatments in each of the three years are shown in Figure 4.2; those for soil potential acid (pH_{HCl})] are shown in Figure 4.3.

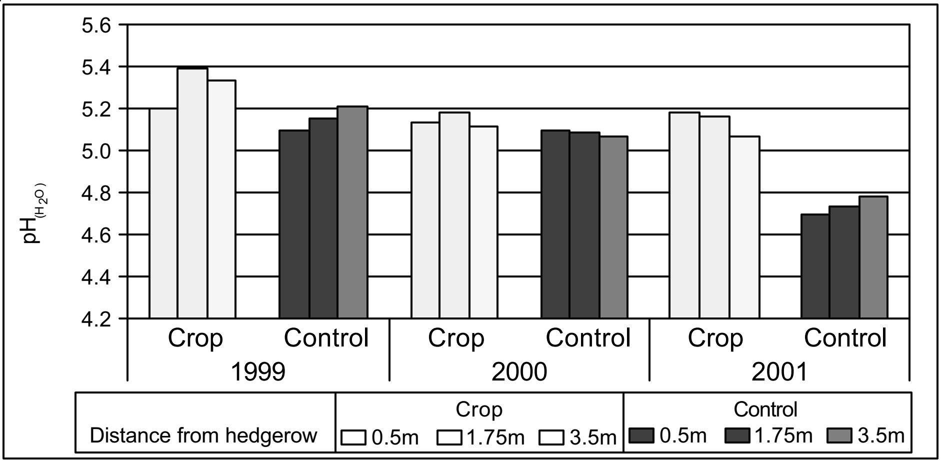

Figure 4.2: Soil active acid

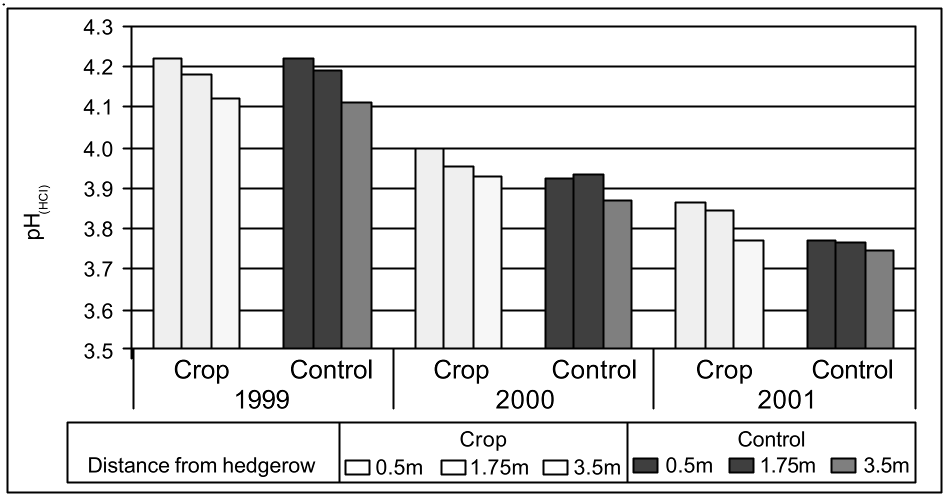

Figure 4.3: Soil potential acid

Soil acidity rarely decreases unless lime or similar materials are applied. Over the three years, there was a slight decrease in soil pH (increase in acidity) which was more marked in the control plots. In all years, the pH values in the plots with crops were slightly higher than in the control plots; the difference was greatest in 2001. This may have resulted from the use of organic fertiliser in the crop plots, but the change in pH value of the control was not significant compared to the crop treatment. In the crop plots, the pH value closest to the hedgerows remained fairly constant, whereas those further from the hedgerows decreased in the first year. In the control plots, the pH values at all distances from the hedgerows decreased.

Figure 4.3 shows clearly that the potential acidity decreased for both treatments in each year. Regardless of whether crops were planted, the soil closer to the hedgerows had a higher potential acidity, indicating that the hedgerows have an impact on this soil characteristic.

Organic matter

The soil content of organic matter for each of the three distances from the hedgerow in the two treatments in each of the three years is shown in Figure 4.4.

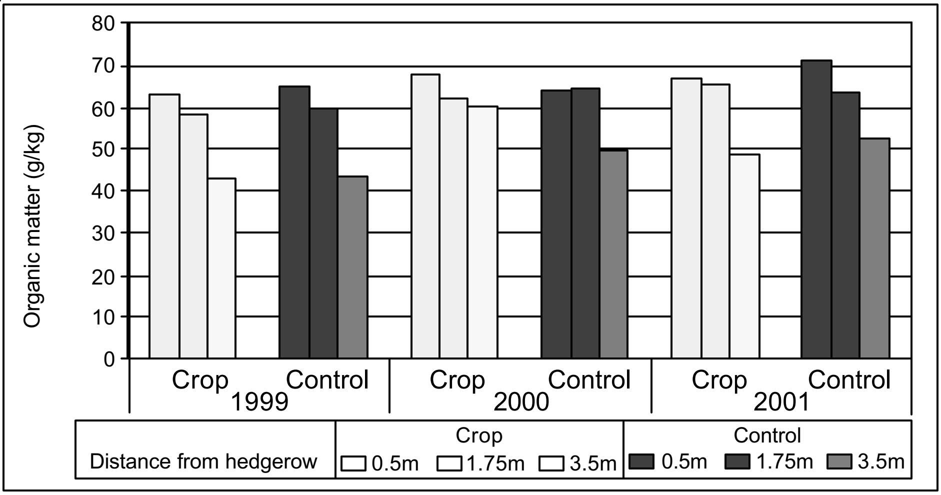

Figure 4.4: Soil organic matter

The soil organic matter content was generally higher close to the hedgerows in all the plots, with or without crops. The difference in the values of soil organic matter at 0.5m or 1.75m from the hedgerows and at 3.5m from the hedgerows was significant in 1999 and 2001 in the crop plots and in 1999 and 2000 in the control plots. There was no significant difference in soil organic matter content at 0.5m and 1.75m from the hedgerow. The soil organic matter content at 0.5 m from the hedgerow increased slightly over the years in both the crop and control plots. The values of soil organic matter were similar in the plots with crops and the control plots.

The results indicate that the hedgerows of nitrogen-fixing plants helped increase soil organic matter, confirming the results reported by Sun Hui et al. (1999). There are two likely reasons: one is the addition of hedgerow clippings and litter into the soil; the other is the decay of roots cut off during ploughing each year. The experimental site was already level, so it is unlikely that organic matter moved from the terrace and accumulated at the base of the hedgerows. Studies on hedgerow systems in the tropics have not identified similar increases in soil organic matter, possibly because organic matter decomposes much faster in the tropics so that there is less residual matter.

Clearly there was no negative competition between hedgerows and crops for soil organic matter rather the opposite; the hedgerows actually increased soil organic matter.

Total nitrogen

The soil nitrogen content for each of the three distances from the hedgerow in the two treatments in each of the three years is shown in Figure 4.5.

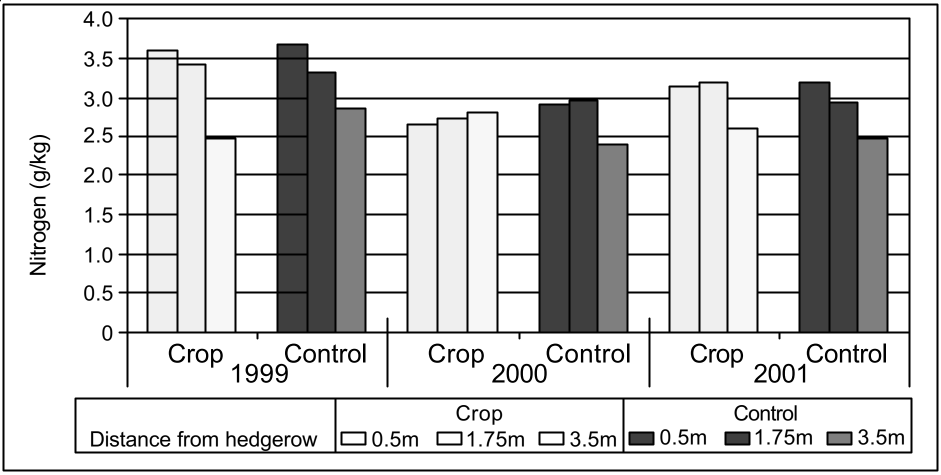

Figure 4.5: Soil nitrogen

The total nitrogen values fluctuated somewhat, mostly decreasing in the first year and remaining constant or slightly increasing in the next. With the exception of the crop plot in 2000, the nitrogen content at 0.5m and 1.75m from the hedgerows was higher than at 3.5m from the hedgerows. The difference was significant in both crop and control plots in 1999 and 2001, in control plots the difference between soils at 0.5m and 1.75m was also significant. There was no significant difference between crop and control plots.

The results indicate that the hedgerows had a positive effect on soil nitrogen. This contrasts with the results obtained in the soil erosion plots, where hedgerows did not show any positive effect on soil nitrogen maintenance compared to traditional farming practice (Chapter 3). The difference may have resulted from the fact that this study was carried out on almost level terrace with well-established hedgerows, whereas the soil erosion plots were established on quite steep sloping land and the hedgerows were just developing.

Available phosphorous

The soil available phosphorous for each of the three distances from the hedgerow in the two treatments in each of the three years is shown in Figure 4.6. The content of total phosphorous is often high in acidic soils, but as a result of the low pH, the available portion is usually very low. The soil available phosphorous varied considerably among years, but in all cases the value was lowest furthest from the hedgerow and, except for the crop plots in 2001, highest close to the hedgerow. The results suggest strongly that hedgerows can improve the availability of soil phosphorous. This could be related to the use of hedgerow clippings, the activity of hedgerow roots, or the segregation by hedgerows of chemicals that improve the availability of soil phosphorous.

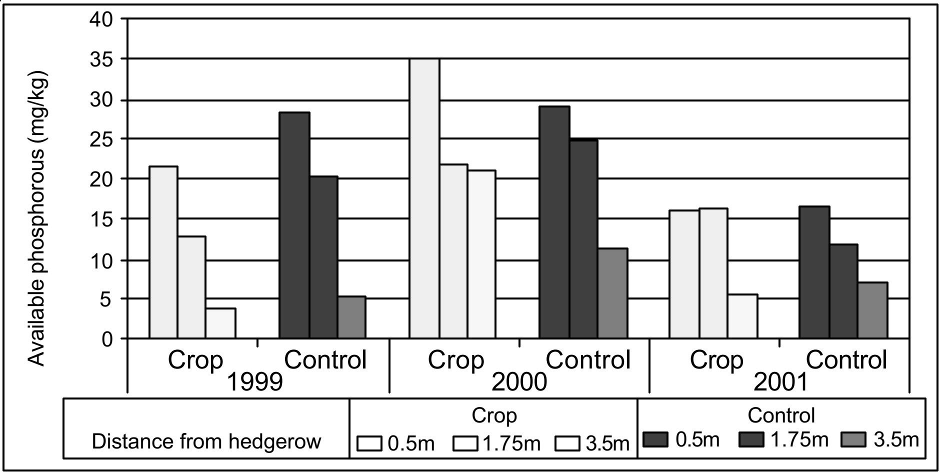

Figure 4.6: Soil available phosphorous

Available potassium

The soil available potassium for each of the three distances from the hedgerow in the two treatments in each of the three years is shown in Figure 4.7. The available potassium decreased every year under both treatments at all positions except for the farthest point from the hedgerow in the crop plots in 2001, a similar pattern to that observed in the soil erosion plots (Chapter 3). The lowest value for available potassium was observed at a distance of 1.75m from the hedgerows in all plots and years, there was no clear pattern for the highest value, however, which was found both closest and furthest from the hedgerow depending on the treatment and year.

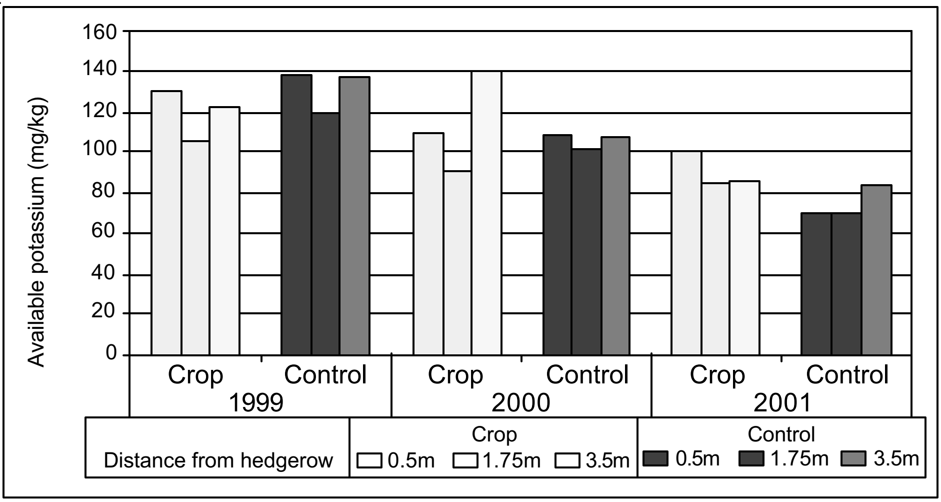

Figure 4.7: Soil available potassium

Crop yield

The average yields of maize and radish in 1999 and 2000 in the three replicate plots is shown row by row in Table 4.1. (The hedgerow alley lay at some distance from the forested area of the site and was at the centre of a series of hedgerow terraces; the crops were not particularly affected by wild animals.)

Table 4.1: Yield of maize and radish (kg/ha)

		Maize		Radish
	Crop row	Biomass	Grain	
1999	1 (Closest to hedgerow)	2,809	409	8,069
	2	3,064	395	6,414
	3	4,124	639	5,979
	4	3,807	906	6,393
2000	1 (Closest to hedgerow)	3,103	598	9,331
	2	2,920	644	8,228
	3	5,030	1,039	7,428
	4	3,301	795	7,834

The results for radish showed a clear pattern with the highest yield from the row closest to the hedgerow, a decrease in yield in the next two rows and a slight increase in yield in row 4 which lay furthest from the bottom hedgerow, but closer to the riser of the upper hedgerow. The higher radish yield correlated with the higher nutrient level closer to the hedgerow.

The results for maize were less clear. There was no direct correlation between biomass production and grain production for the maize – more biomass was not necessarily associated with more grain – which further complicated the interpretation of the results. Even so, for both biomass and grain, there was a higher yield in rows 3 and 4, furthest from the hedgerow, than in rows 1 and 2, closest to the hedgerow, with a tendency to lower yields in row 4, closer to the next hedgerow riser, than in row 3. This is the opposite of the results obtained with radish, although statistical analysis indicated that the differences were not significant (Chapter 5).

Other authors have reported significant affects of hedgerows on crop yield: with much lower grain and biomass production closer to hedgerows. For example, Salazar et al. (1993) reported that crop yields in the rows closest to the hedgerows were reduced by up to 60% compared to more distant rows, and there are many similar reports (Lawson and Kang 1990; Fernandes et al. 1990; Basri et al. 1990, Evensen and Yost 1990). The results for maize in the present study are similar to those in these earlier reports, but those for radish are the direct opposite.

Fresh biomass of hedgerow clippings

The annual fresh pruned biomass from the upper row of the double hedgerow and the lower row of the double hedgerow is given in Table 4.2.

The quantity of biomass produced by the hedgerows is likely to be the most important factor contributing to fertility changes in a hedgerow intercropping system. As discussed in Chapter 3, the production of fresh biomass (5.3t/ha) was much lower than the 8-14 t/ha reported for other species in the HKH region (Sun Hui et al. 2001). Selection of other fast growing hedgerow species is needed.

Table 4.2: Fresh biomass of hedgerows of ***Alnus nepalensis*** (t/ha)

	1998	1999	2000	2001	Average
Upper hedgerow	2.6	2.8	3.0	3.2	2.9
Lower hedgerow	2.3	2.1	2.5	2.8	2.4

Discussion

One of the significant advantages of contour hedgerow intercropping is the improvement of soil fertility that is gained through the continuous addition of hedgerow clippings to the soil. Nitrogen-fixing plants are used for the hedgerows as they can fix nitrogen from the atmosphere in the form that plants can use. Most of the perennial woody nitrogen-fixing plant species that have been used to establish hedgerows are fast growing. However, fast growth also implies a need for nutrients from the soil. Fear of above ground and below ground competition between hedgerows and crops for light, soil nutrients, and soil moisture – and a resultant reduction in crop yield – was one of the major reasons given for farmers not adopting the technology (Böhringer and Leihner 1997). Farmers in Ningnan in Sichuan Province, China, also considered that the hedgerows grow so fast that they must use up most of the nutrients in the alley, and were sure that crops in the alley would not grow well. Competition for nutrients has been regarded as a cause of reduced crop yield in many tropical areas. But there have been reports of both positive (Leihner et al. 1996) and negative effects (Singh et al. 1989) of hedgerows on crop production.

The results of this study indicate that there was no competition between hedgerows and crops for most soil nutrients in an established hedgerow system. On the contrary, the hedgerows contributed to improving soil fertility: the highest content of many nutrient elements was found closest to the hedgerow, especially organic matter, nitrogen, available phosphorous, and a number of exchangeable cations. If there was competition, the lowest content should have been found closest to hedgerows.

However, the crop yield did not correspond directly with the nutrient status of the soil at different distances from the hedgerows. The fresh yield of radish was higher closer to the hedgerows, as expected, but the yield of maize was not. The difference may be because radish is sensitive to phosphorous, and thus the yield was best where the phosphorous values were highest. Maize may be more sensitive to other factors like light (shading) and moisture that have a more significant effect than the effect of the better pool of nutrients close to the hedgerows.

The nutrient contribution from the hedgerow clippings was not significant. We did not analyse the nutrient composition of the *Alnus nepalensis* used in this study, but the N content of the leaves can be estimated from analyses of this and similar species in other parts of the region (Deng Ting-xiu; Liu Guo-fan 1987; Sharma et al. 1994). These analyses indicate that young leaves have a nitrogen content of 2.6 to 3% (dry matter). An average of 45.5 kg/year of fresh hedgerow clippings, or around

11.5 kg dry matter (estimated using a moisture content of 75%), were added to the experimental plots, indicating an addition of around 0.30 kg of nitrogen for the whole experimental alley of (42.3 x 5m or 187 m^2), equivalent to 16-19 kg/ha per year.

Conclusions

The results of the study suggest that there is no competition between hedgerows and crops for underground soil nutrients. The soil content of most nutrients was higher closer to the hedgerows suggesting that the *Alnus nepalensis* hedgerows actually improved the soil nutrient status. The reduced maize yield closer to the hedgerows, though insignificant statistically, might be the result of shading. The soil nutrient status in the same alley needs to be studied again (preferably after 5 and 10 years) to properly elucidate the effects.

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Chapter 5

Competition for Soil Moisture Between Hedgerows and Crops in a Contour Hedgerow Intercropping System

Philippe Jobin and Tang Ya

INTRODUCTION

Water is a major limiting factor for crop production, especially in arid and semiarid regions and regions with a long dry season. Nepal has a typical monsoon climate characterised by a dry season of about 7-8 months, during which only some 20% of annual precipitation falls. A large part of the agricultural land in Nepal is rainfed: more than 1 million hectares of cultivated land in the hill and mountain areas has no irrigation (Tulachan 2001). The major problem with farming sloping cropland is soil erosion. Terracing is the response of mountain people to this problem; it is widely used for cultivation in slope areas (Ojha 1997). Around 30% of the erodible agricultural land in the hills of Nepal (365,000 ha) has been terraced (Yadav 1998). This practice is effective in retaining rainfall water on terraces (Stallings 1957), which controls runoff and hinders soil erosion (Finkel 1986).

Sloping agricultural land technology (SALT), also known as contour hedgerow intercropping technology (CHIAT), is an effective alternative to the classical man-made terrace. It has almost all the functions of a hand cut terrace, but the terraces are developed by planting fast growing perennial woody tree or shrub species along contour lines. The hedgerows create a living barrier that traps sediments and gradually transforms the sloping land to terraced land forming a 'bioterrace'. Bioterracing involves important modifications to the land over time and the incorporation of trees and shrubs into the agricultural system is certain to lead to a number of changes; there could be a redistribution of soil water in the soil profile, for example. Another common criticism of SALT is the possibility of competition with crops for limited water resources. There have been several reports from tropical areas that indicate that moisture competition between hedgerows and associated crops can be a major problem when a hedgerow intercropping system is used in a dry area, particularly when the hedgerows are closely spaced (Singh et al. 1989), and that this can reduce crop yield.

ICIMOD, in collaboration with national institutions, has introduced the contour hedgerow technology to the subtropical to warm temperate areas of the HKH region. The climate and water resource regime prevailing in the HKH region are different from those in the tropics. Since the productivity of rainfed land during the dry season is strongly dependent on the moisture available to the crop, it is important to determine whether or not there is a competition between hedgerows and crops in this different climate.

In the following, we describe the results of an experiment to quantify the soil moisture relationship between hedgerows and companion crops at a site in the mid hills of Nepal. The main aim was to investigate the spatial moisture distribution in a terrace developed by planting hedgerows of *Alnus nepalensis,* and to determine whether there was any competition between the hedgerow and the crop for the water resources by means of modelling.

Material and Methods

Site description

The experiment was conducted at ICIMOD's Godavari Trial and Demonstration Site (see Chapter 1) on a rainfed outwardly-sloping terrace (around 5 degrees) established with hedgerows of *Alnus nepalensis* (utis). The hedgerows had been established with seedlings in 1993 and occupied about 17% of the land space of the terrace.

Experimental design

The experiment was carried out in parallel with the experiments on nutrient competition described in Chapter 4.

The experiment consisted of two treatments with three replicates. Treatment 1 was with cultivation of crops and Treatment 2 without crops. The two treatments were arranged alternately along one alley with a gap between treatments. For the treatment with crops, maize was sown in April and harvested in September, and radish was sown in October and harvested in March. The first crop, radish, was sown in September 1998 and the last crop, also radish, was sown in October 2000. The crops were planted in rows (C1 and C2 in Figure 5.1). A locally purchased concentrated organic fertiliser 'kisan mal' was applied to the treatment plots with crops at a rate of 16 t/ha (1.6 $kg/m^{2)}$ for each planting season before sowing; its nutrient composition is 3% N, 5% $P_2O_{5,}$ and 2% K_2O (see Chapter 2).

The maize crop was harvested and the fresh weight of crop biomass and the grain weight determined. Samples were taken for oven-drying to obtain the weight of dry matter. Only the fresh weight of radish was determined.

The soil water content was followed indirectly using soil tension measurements performed with a tensiometer gauge (H&TS Electronics Ltd, Healesville, Australia) and tensiometer tubes. The tensiometer tubes were placed at three positions of increasing distance from the hedgerow in between the rows of crops as shown in Figure 5.1: P1 (20 cm from hedgerow), P2 (140 cm from hedgerow), and P3 (260 cm from hedgerow). The tubes were placed at four depths at each position: D1 = 10 cm, D2 = 30 cm, D3 = 50 cm, D4 = 70 cm (Figure 5.1). The tensiometers were not disturbed by the soil sample collection that was performed in parallel (see Chapter 4 and Figure 4.1). The soil tension data collection started in June 1999 and was continued at five-day intervals until December 2000.

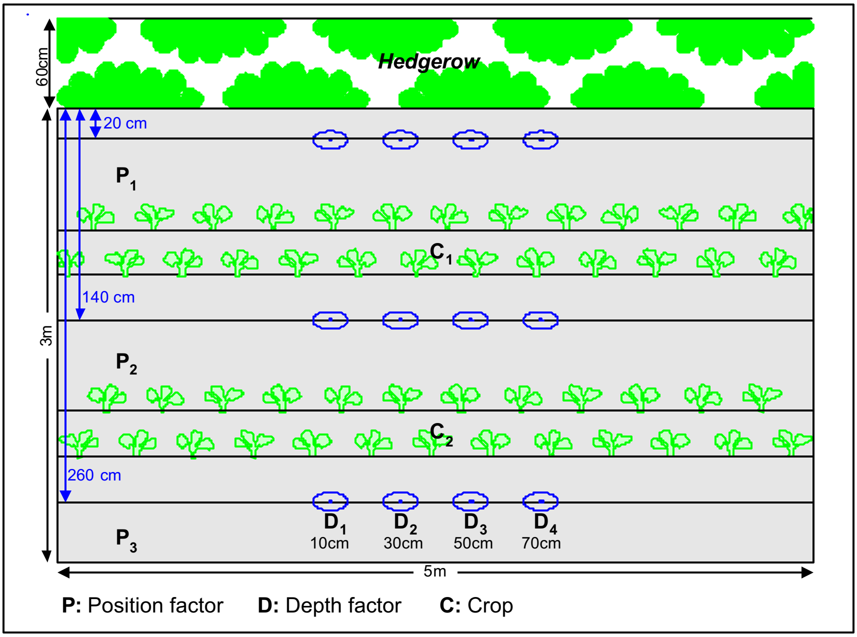

Figure 5.1: Experimental design (one block)

The design was a split block with three replicates. The treatment structure was factorial with the Position in the main plot, and the Depth and Time in a subplot. The statistical analysis was performed with Genstat Second Edition™ software. An analysis was performed for the complete data set, and for the dry season and rainy season data separately. The homoscedasticity and normality were verified using a residual versus fitted values plot and a histogram of residuals, respectively.

Modelling

The potential competition for water between hedgerow and maize was investigated by estimating the water consumption of each. The consumptive use of water was determined with an empirical method based on the Penman-Monteith approach (Verhoef and Feddes 1991). The potential evapotranspiration was determined from the following formula (Feddes and Lenselink 1994):

$$ET_p = K_c \, ET_h \qquad (1)$$

Where

ET_p = potential evapotranspiration
K_c = crop coefficient
ET_h = reference evapotranspiration

The hedgerow coefficient was estimated as 1.0 based on a tea crop with more than 70% ground cover (Doorenbos and Pruitt 1977). A maize coefficient of 0.86 was assumed (Arora 1996). The reference evapotranspiration was calculated from the following formula (Verhoef and Feddes 1991):

$$ET_h = \left(\frac{\Delta}{\Delta + \gamma *}\right) R'_n + \left(\frac{\gamma}{\Delta + \gamma *}\right) E_a \quad (2)$$

Where

ET_h = reference crop evapotranspiration rate (mm/d)
Δ = slope of vapour pressure curve at T_a (kPa/°C)
γ = psychrometric constant (kPa/°C)
γ^* = modified psychrometric constant (kPa/°C)
R'_n = radiative evaporation equivalent (mm/d)
E_a = aerodynamic evaporation equivalent (mm/d)

The reference evapotranspiration term was calculated assuming a crop average height of 60 cm, a canopy reflection coefficient (albedo) of 0.23, and a canopy resistance equal to 70 s/m.

The computation method required the following meteorological data:

minimum and maximum temperature (°C)
solar radiation (W/m^2)
relative duration of bright sunshine (-)
average relative humidity (%)
wind speed (m/s)

These parameters were collected from a meteorological station located at about 250m from the experimental site, except for the solar radiation, which was estimated from the following equation (Feddes and Lenselink 1994):

$$R_s = \left(a + b\frac{n}{N}\right) R_A \quad (3)$$

Where

R_s = Solar radiation (W/m^2)
a = fraction of extraterrestrial radiation on overcast days (-)
a + b = fraction of extraterrestrial radiation on clear days (-)
R_A = extraterrestrial radiation, or Angot value (W/m^2)
n = duration of bright sunshine (h)
N = day length (h)

The potential evapotranspiration term was calibrated by a factor of 0.50 to take into account the fact that the hedgerow has an effect on soil moisture further from its canopy. The hedgerow's canopy (500m x 0.60m) covered a surface of 300m^2. The surface area explored by the roots is approximately 600m^2 (1.20m x 500m). The 1.20m value was determined by excavating *Alnus nepalensis* plants. The calibration factor was obtained from the ratio between the surface covered by the hedgerow and the surface explored by the roots (300m^2 / 600m^2 = 0.50).

The potential evapotranspiration of the hedgerow, expressed in millimetres, was transformed into volumetric water content using the following equation (Musy and Soutter, 1991):

$$\theta_v = \frac{ETp}{(a-b)} \qquad (4)$$

Where

- q_v = volumetric water content (vol/vol per day)
- ET_p = potential evapotranspiration (mm/d)
- a–b = depth of soil explored by the roots (mm)

Excavation of *Alnus nepalensis* plants showed that the roots could extract water up to 800 mm from the surface (a = 800 and b = 0); a rooting depth of 700 mm was assumed for maize. The modification of the volumetric water content of soil per day resulting from the evapotranspiration of the maize and the hedgerow is shown in Table 5.1.

Table 5.1: Modification of the volumetric water content of soil per day resulting from the evapotranspiration of maize and hedgerow

Month and year	Maize[1] (vol/vol)	Hedgerow[2] (vol/vol)
October 1999	0.0022	0.0011
November 1999	0.0020	0.0010
December 1999	0.0010	0.0005
January 2000	0.0017	0.0009
February 2000	0.0027	0.0014
March 2000	0.0044	0.0022
April 2000	0.0053	0.0027
May 2000	0.0036	0.0018

[1] Calculated for a depth of 70 cm; [2] Calculated for a depth of 80 cm

The soil tension data from P1 and D2 in the treatment plots were transformed into volumetric water content (q_v) using the characteristic moisture release curve of the soil. This moisture curve was obtained from simultaneous measurements of the volumetric water content, performed with a probe using dielectric permittivity technology (Campbell Scientific, Utah, USA), and the soil tension, performed with a tensiometer gauge (H&TS Electronics Ltd, Healesville, Australia) and tensiometer tubes. The moisture release curve was calculated for the 5 to 25 cm layer of soil (Figure 5.2). The water loss by evapotranspiration by the hedgerow and the maize was added or subtracted, respectively, to the volumetric water content measured in P1 and D2 in the plots without crops ('with hedgerow, no maize') then reconverted into tension data. This process allows the moisture conditions to be estimated for the following combinations: 'with hedgerow, with maize', 'no hedgerow, with maize', and 'no hedgerow, no maize'.

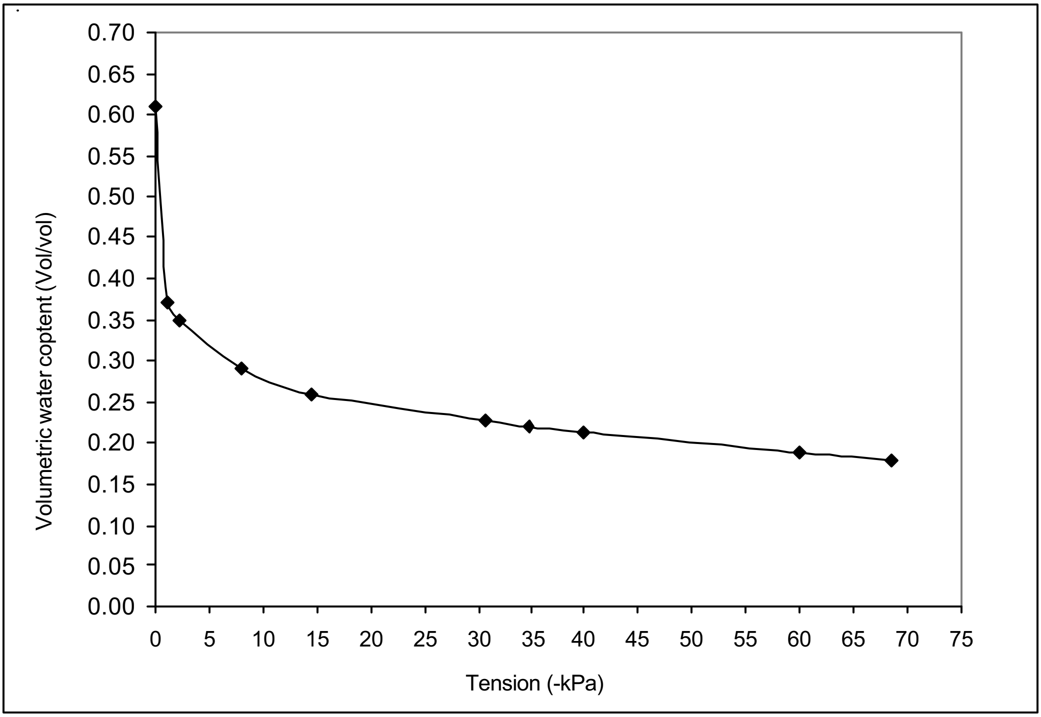

Figure 5.2: Moisture release curve (desorption) of the soil

Results

Soil moisture

The soil moisture tension measured by tensiometers at depths of 10 cm, 30 cm, 50 cm, and 70 cm for the period from 20 May 1999 to 9 January 2001 for the two treatments are shown in Figures 5.3 to 5.10.

During the monsoon, the soil tension was very low at all four depths in both treatments; this is because the soil is saturated during this period. There is more than sufficient water for crop growth, and there is no competition for water during the monsoon.

Competition for soil water only occurs during the dry season. The trend in change of soil tension was similar for both treatments at the same soil depth. The only difference was that soil tension increased slightly more rapidly with cultivation of radish than in the treatment without a crop at depths of 10 and 30 cm; at depths of 50 and 70 cm, the soil tension trend was similar. In other words, the soil moisture in the treatment with radish was slightly lower than in the treatment without radish.

The trend in soil tension was similar in both treatments. From early October, when the monsoon ceased, the soil tension increased rapidly; the highest soil tension was

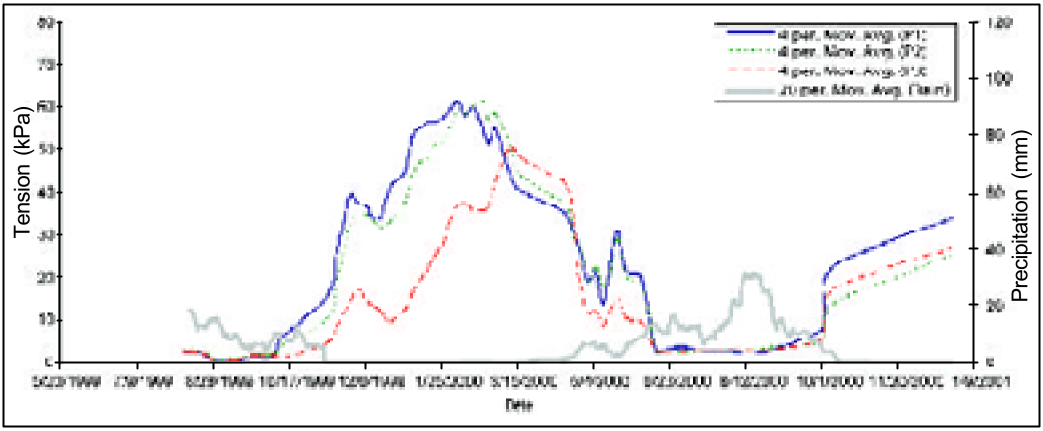

Figure 5.3: Soil tension at 10 cm, treatment without crop

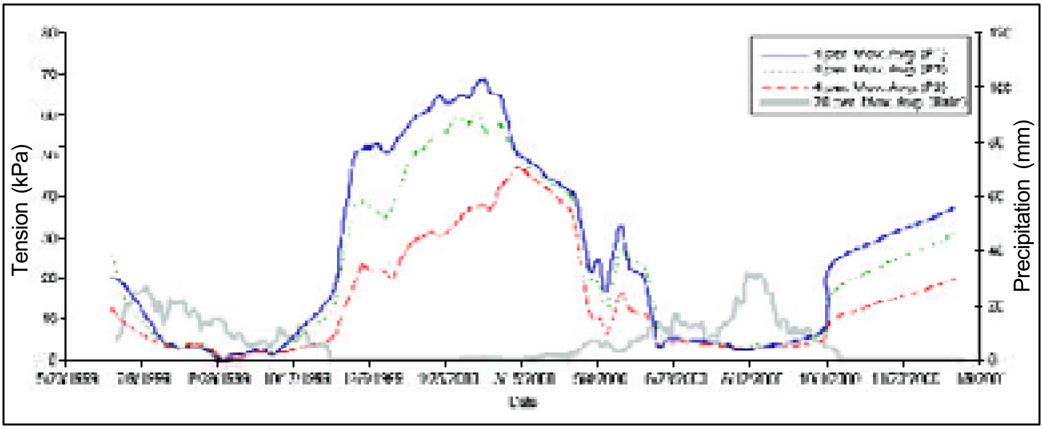

Figure 5.4: Soil tension at 10 cm, treatment with crop

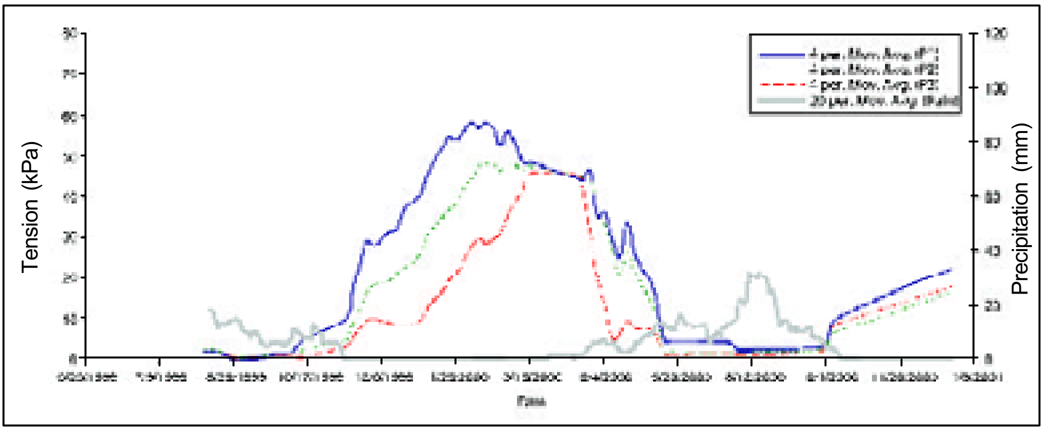

Figure 5.5: Soil tension at 30 cm, treatment without crop

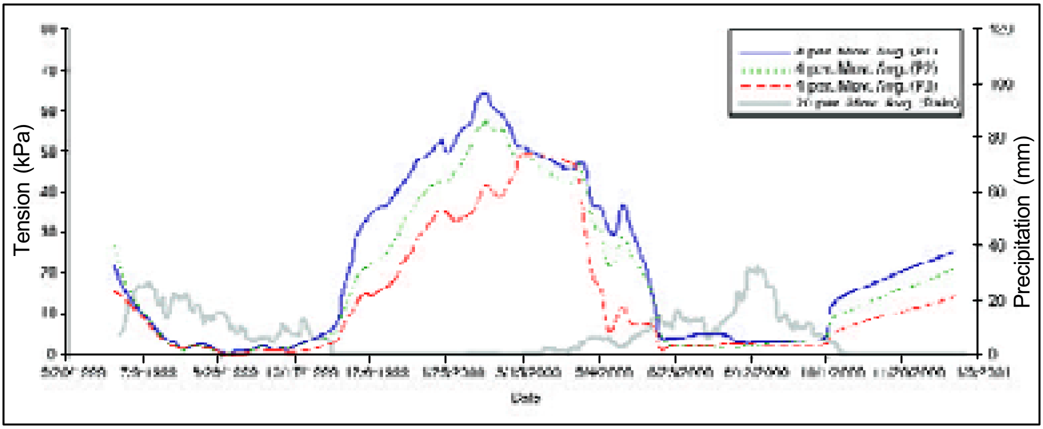

Figure 5.6: Soil tension at 30 cm, treatment with crop

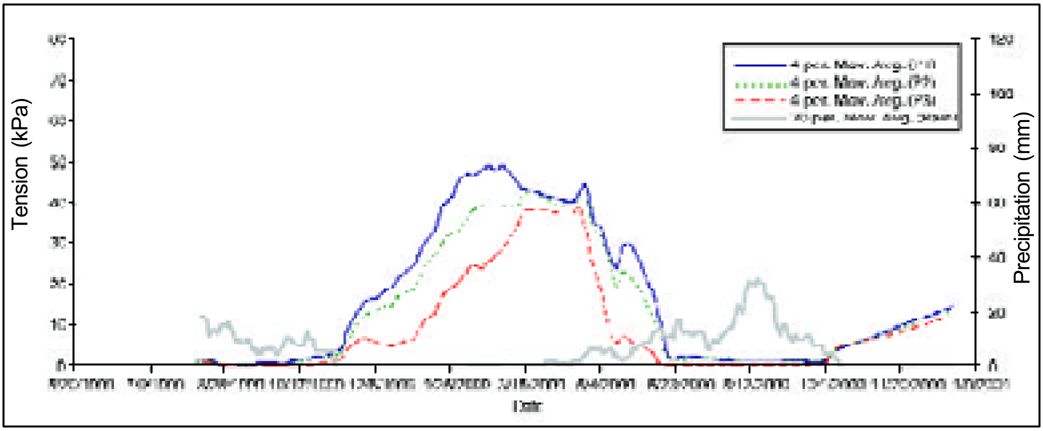

Figure 5.7: Soil tension at 50 cm, treatment without crop

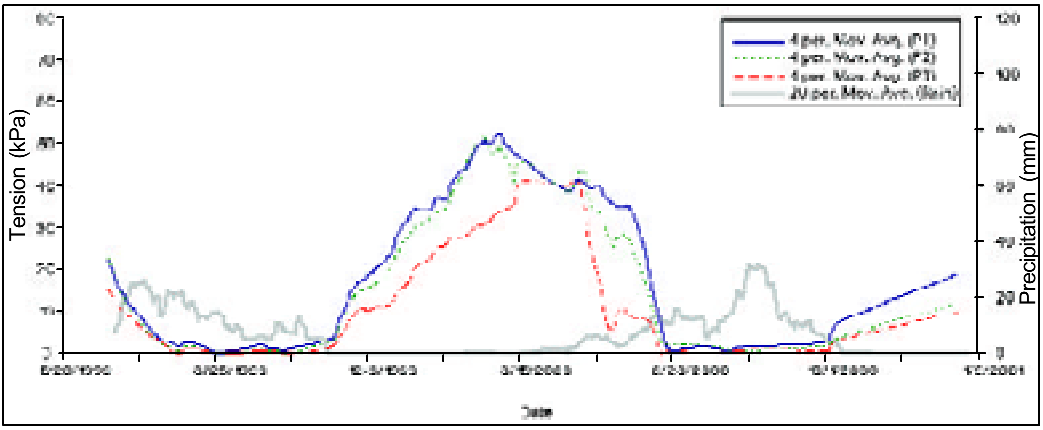

Figure 5.8: Soil tension at 50 cm, treatment with crop

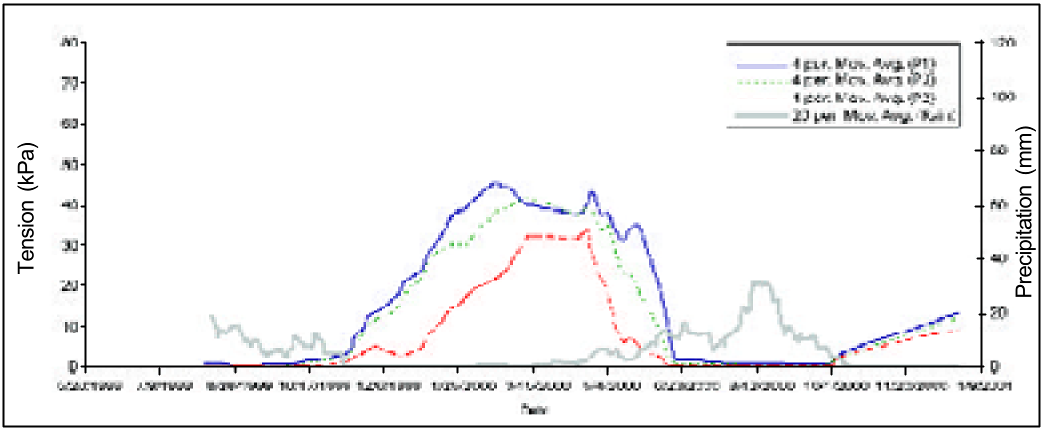

Figure 5.9: Soil tension at 70 cm, treatment without crop

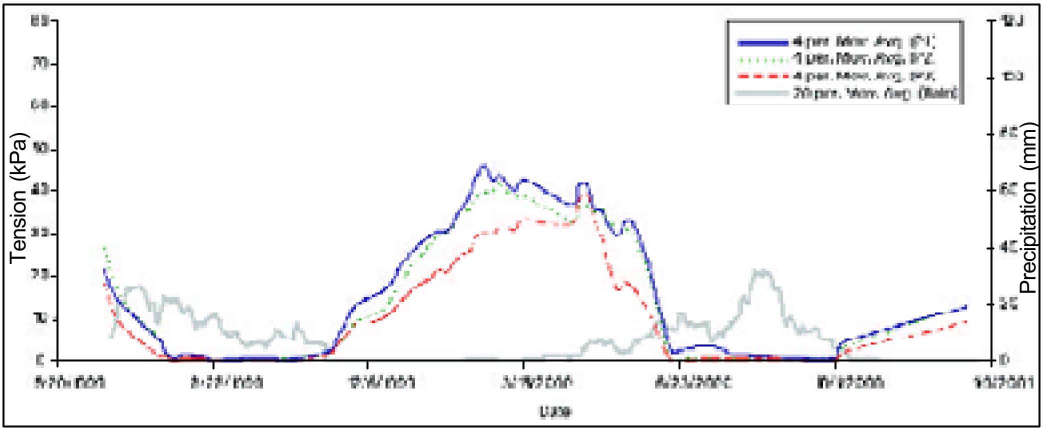

Figure 5.10: Soil tension at 70 cm, treatment with crop

observed during February and March and it decreased thereafter. Premonsoon rain led to a rapid decrease in soil tension, which was accelerated when the monsoon started properly. The deeper the soil depth, the lower was the soil tension; the increase in soil tension was not as rapid at lower depths as at a depth of 10 cm. This means that the top 10 cm soil became dry very fast, mainly because of evaporation; deeper down the soil dried more slowly.

The soil tension also decreased with increased distance from the hedgerow for all four depths in both treatments. The decrease with distance was more marked near the surface and less at greater depths.

Root competition between crops and hedgerow plants takes place in the top layer from 0-50 cm, thus the results indicate that there was competition between hedgerows and crops for soil moisture during the dry season.

There was a significant double interaction between the Position and the Depth factors (Table 5.2). This means that during the dry season the soil moisture content increases as the depth of soil increases; and the moisture content decreases closer to the hedgerow (Figures 5.3 to 5.10). These two effects are combined and produce a water distribution as shown in Figure 5.11. The moisture gradient direction, represented by the double-headed arrow, is from the topsoil close to the terrace hedge (driest) to the deep soil close to the back base of the terrace (wettest). When the rain starts, this interaction is no longer significant, as shown in Figures 5.3 to 5.10 by the convergence of the P1, P2, and P3 lines.

Table 5.2: Analysis of variance of a split block design for the tension variable

	Complete data		Dry season data		Rainy season data	
Source of variation	df[1]	F[2]	df	F	df	F
Repetition	2	2.2	2	2.1	2	2.5
Position	2	5.0	2	4.6	2	9.6*
Error A)	4		4		4	
Depth	3	24.3**	3	20.7**	3	16.51**
Time	68	33.5**	37	15.7**	30	98.6**
Error B)	141		79		66	
Position x Depth	6	9.2**	6	11.0**	6	0.7
Position x Time	136	4.8**	74	2.6**	60	5.22**
Depth x Time	204	5.4**	111	6.0**	90	2.75**
Position x Depth x Time	408	0.9	222	0.9	180	0.8
Error C)	1458		778		670	
Total	2432		1318		1113	

Note: Only the most complex interactions need to be considered in the analysis.
[1] degrees of freedom; [2] F value; * F value significant at 0.05; ** F value significant at 0.01

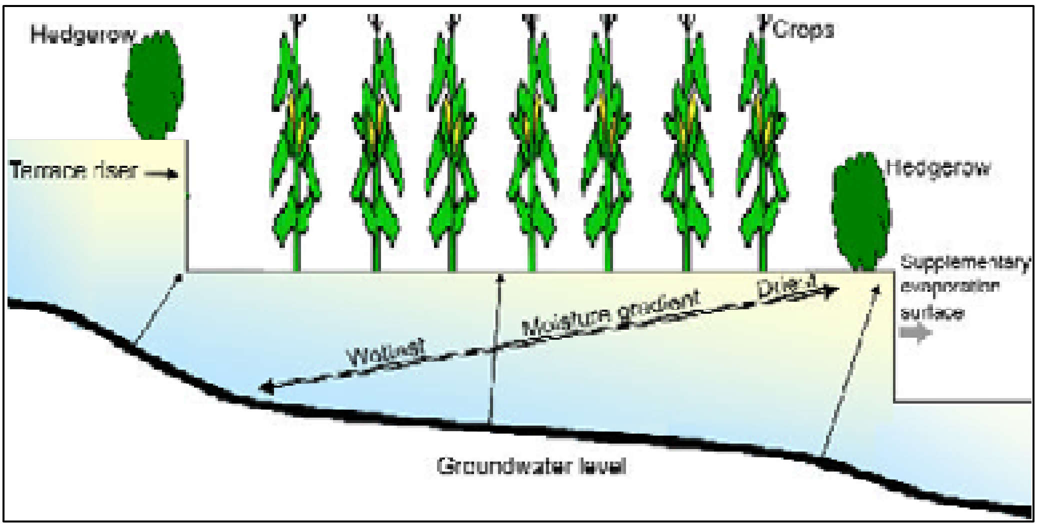

Figure 5.11: Distribution of moisture in the soil profile of a terrace during the dry season

The two other significant double interactions are between Depth and Time and Position and Time factors. They are significant for both rainy and dry seasons. These interactions indicate that the difference between the levels of Position and Depth factors are not constant over time, resulting in their convergence or divergence depending on the precipitation distribution.

Growth of maize

The maize yield for the positions C1 and C2 is shown in Table 5.3. The grain mass of maize in C1 was 91 and 48% lower than that in C2 in 1999 and 2000, respectively, and the biomass 31 and 33% lower. This indicates that the competition with the hedgerow has a negative impact on both crop biomass and crop yield. However, the statistical analysis indicated that differences in weight were not significant (Table 5.3).

Table 5.3: Fresh weight of biomass and grain for maize in 1999 and 2000

Position[1]	1999		2000	
	Biomass (kg)	Grain (kg)	Biomass (kg)	Grain (kg)
C1	7.45	1.17	7.67	1.80
C2	9.77	2.24	10.20	2.66
Probability[2]	0.216	0.084	0.076	0.144

[1] C1 was close to the hedge and C2 was far from the hedge.
[2] Probability associated with one degree of freedom for the treatment and 4 degrees of freedom for the error term.

Modelling

The evapotranspiration rates (millimetres per day) for the hedgerow and the maize are shown in Table 5.4. The evapotranspiration was 1.72 times higher for the maize than for the hedgerow (corrected values). Figure 5.12 shows that when there is a maize crop, the soil tension differences between the presence or not of a hedgerow can reach 37 kPa (in April). Drier conditions occur for about four to five weeks (mid-March to mid-April) when there is a contour hedgerow present.

Table 5.4: Climate data and evapotranspiration calculation

Godavari (altitude 1,634m)

Month	[1]T_{max}	[1]T_{min}	[2]R_s	[3]n	[4]N	n/N	[5]RH	[6]u_2	[7]ET_h	[8]ETp* Hedgerow	[9]ETp Maize	ETp_{maize} / ETp* hedgerow
	(°C)	(°C)	(W/m²)	(h)	(h)	(-)	(%)	(m/s)	(mm/d)	(mm/d)	(mm/d)	(-)
Oct. 1999	25.6	10.5	144	4.65	8.04	0.58	94	0.48	1.76	0.88	1.51	1.72
Nov. 1999	26.4	6.5	157	5.58	7.30	0.76	94	0.71	1.64	0.82	1.41	1.72
Dec. 1999	20.6	3.5	100	3.94	7.29	0.54	93	0.72	0.83	0.41	0.71	1.72
Jan. 2000	18.8	2.0	161	6.08	7.42	0.82	87	0.75	1.39	0.70	1.20	1.72
Feb. 2000	19.0	2.6	229	6.92	7.08	0.98	84	0.83	2.22	1.11	1.91	1.72
Mar. 2000	25.2	9.9	268	7.92	8.39	0.94	79	0.86	3.56	1.78	3.06	1.72
Apr. 2000	29.8	15.5	271	7.22	8.66	0.83	80	0.71	4.29	2.14	3.69	1.72
May 2000	30.1	15.5	183	4.96	9.42	0.53	90	0.56	2.90	1.45	2.49	1.72

[1] Maximum and minimum temperatures; [2] Solar radiation; [3] Duration of bright sunlight; [4] Length of day; [5] Relative humidity; [6] Wind speed; [7] Reference evapotranspiration; [8] Corrected potential evapotranspiration for the hedgerow (by a factor of 0.50); [9] Potential evapotranspiration for the maize crop

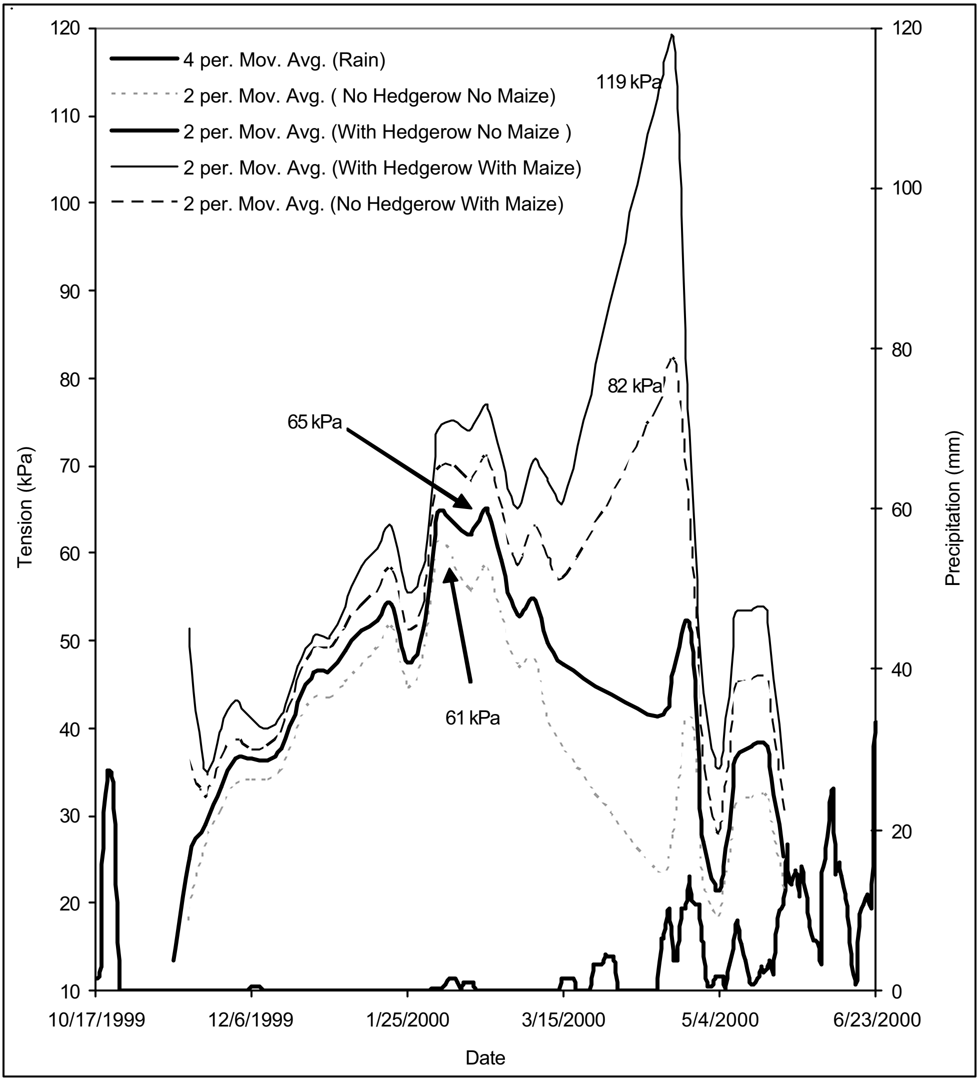

Figure 5.12: Estimated soil tension (from model calculations

Discussion

Hedgerow tree roots can compete with crop roots for available water and nutrients in the topsoil. Alley cropping experiments in semi-arid India demonstrated significant water competition between *Leucaena leucocephala* hedgerows and castor, cowpea, and sorghum crops (Singh et al. 1989). Crop yields declined from 30 to 150% of the crop at the sole of the terrace when the distance from the hedge was reduced from 5 to 0.3 m. Competition for water is often considered more important than shading effects under arid and semi-arid conditions; in the humid tropics water is not as limiting as nutrients in the soil.

The present study of soil tensions in a bioterrace showed that the moisture distribution was not uniform. The practical implication is that growing crops close to the edge of the terrace could be affected by prevailing dry conditions. In this experiment, the maize growth was not significantly affected by its location on the terrace. This might be because of the small number of repetitions, which meant that there were only four degrees of freedom for the error term. However, the absence of a significant effect on maize growth is more likely to be due to the excess of water available to the crop during the rainy season. This was shown by the soil tension distribution which showed no significant differences for the soil tension between the three positions on the terrace during the maize growing period. Further, when the situation for water is considered together with the results for soil nutrient research (Chapter 4), it becomes clear that the competition for water between hedgerows and maize might be sidelined by the higher nutrient conditions closer to the hedgerows.

The moisture gradient during the dry season can be attributed, in part, to the particular morphology resulting from the terracing (Figure 5.11). The distance between the groundwater and the topsoil increases closer to the edge of the terrace, and the terrace riser provides a supplementary evaporation surface which also enhances the moisture gradient in the terrace. The other factor that possibly enhances the moisture gradient is the presence of the hedgerow. One criterion for hedgerow species selection is that the root system is deeply anchored in the soil to assure nutrient cycling from the deep soil to the surface and avoid water competition with crops. Excavation of *Alnus nepalensis* plants showed that the hedgerow's roots explore 40% of the terrace surface at a depth of 0.80m. The results of the modelling exercise (Figure 5.12) indicate that the hedgerow enhances the soil tension on this portion of the bioterrace. The differences between the curves with and without hedgerow increase progressively to reach a peak around the 20th of April when there is a hypothetical maize crop, and around the 20th of February for the bare soil. This is explained by a high evapotranspiration demand during March and April, a period when the sporadic rainfall is not sufficient to reduce the soil tension in the way it does for bare soil. Another obvious difference is the relative impact of the hedgerow on the soil tension depending on the presence of a crop. This is attributed to the characteristic form of the moisture release curve (Figure 5.2), which shows that the extraction of water produces a more marked increase of the soil tension (created by the maize evapotranspiration) under dry conditions than under wet conditions.

Since the hedgerow contributes to enhancing the moisture gradient on the bioterrace, it is possible that competition could take place between the hedgerow and the crop. Kabat and Beekma (1994) indicate that plant growth begins to be limited by the soil moisture conditions at between 40 and 100 kPa of tension. As our results were from estimations, it is hazardous to predict that yields will be reduced. A specific field experiment is needed for this.

An experiment carried out by Singh et al. (1989) indicated that root and light competition between hedgerows and crops could lead to a reduction in yield of sorghum and cowpea by 70%. Their study also indicated that root competition is greater than light competition, in that sorghum and cowpea adjacent to the hedgerows experienced intense shading, but with a root barrier in place yielded almost the same as the crops distant from the hedgerow. Experiments have demonstrated that competition for soil moisture is strong and leads to a reduction in crop yield (Singh et al. 1989; Ong and Black 1994). In our study we also observed a reduction in the maize crop closer to the hedgerow, but there was an increase in the fresh radish yield (Chapter 4).

The effect of hedgerows on soil moisture is different in different regions. One study found that soil moisture at 0-5 cm depth was higher in the vicinity of hedgerows than in non-agroforestry (hedgerow) systems, which was attributed to the effect of shade and reduced soil-moisture evaporation (Lal 1989). However, this study was over a rather short period and a long term study is needed for a concrete conclusion.

Conclusion

This experiment clearly demonstrated the existence of a moisture gradient on the terrace surface during the dry season. This gradient disappeared during the rainy season. The moisture gradient was attributed both to the particular morphology resulting from the terracing and to the presence of the hedgerow. The modelling exercise showed that an *Alnus nepalensis* hedgerow increased the moisture gradient on 40% of the terrace. Further studies should be performed to investigate the potential effect of introducing a contour hedgerow on the water available to the crop and the effect on the yield.

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