Performance and Selection of Nitrogen-Fixing Hedgerow Species

Tang Ya
Suraj B. Thapa

Godavari ICIMOD

Focus on Godavari #4

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.

Available titles (December 2004)

- #1 Seeing is Believing: the ICIMOD Demonstration and Training Centre, Godavari (forthcoming)
- #2 Nature's Bounty: Nitrogen-Fixing Plants for Mountain Farmers
- #3 Impact of Contour Hedgerows: A Case Study
- #4 Performance and Selection of Nitrogen-Fixing Hedgerow Species
- #5 Perennial Cash Crops for Mountain Areas (forthcoming)

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International Centre for Integrated Mounain Development
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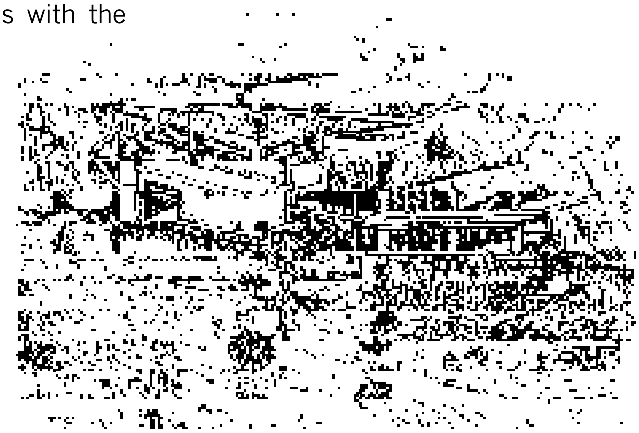
Foreword
Focus on Godavari

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. Sloping agricultural land technology (SALT), also known as contour hedgerow intercropping (agroforestry) technology (CHIAT), is a technique that when successful simultaneously reduces soil erosion and improves soil fertility. 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.

Selection of appropriate species for the hedgerows is a key factor for the successful establishment of a contour hedgerow intercropping system. Nitrogen-fixing plants are recommended for most areas because they can grow in very poor soil, they grow fast, and they produce high quality fodder, as well as directly contributing to improving soil fertility in the alleys. Until now, however, most research on alley cropping or contour hedgerow intercropping has focused on a limited number of species, and most species selection studies have been aimed at tropical areas with only a few studies in subtropical areas.

The goal of species selection for a hedgerow system is to put the right species in the right place. An experiment was carried out at ICIMOD's Demonstration and Training Site at Godavari from 1993 to 2001 to test different nitrogen-fixing species and select plants suitable for establishing contour hedgerow systems in the HKH region in areas with similar agro-ecological conditions. The results of the tests for screening and selection of appropriate nitrogen-fixing plants and other multipurpose plant species are described in detail in the present publication.

Of the 24 species tested, five were finally recommended for use as hedgerow species in the Himalayan mid-hills. Many originally promising species proved to be unsuitable in the long-term, showing again how important it is to carry out proper trials over an extended period. Four of the five recommended species are local species, and the fifth a locally adapted species, indicating the need to test as many local species as possible in other regions in the future.

I hope this book 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.

Eklabya Sharma
Programme Manager
Integrated Programme on
Natural Resource Management

Executive Summary

Contour hedgerow intercropping technology, or sloping agricultural land technology, has been promoted as a tool to facilitate sustainable management of sloping agricultural land. The key factor for successful application of this technology is the selection of appropriate nitrogen-fixing plant species to establish the hedgerows. Past investigations and trials have focused on tropical areas and a limited number of species. Extension of the technology to subtropical and temperate areas brings with it the need to screen other species for their potential as hedgerow species in these cooler climates; most of the hedgerow species currently used in tropical regions cannot grow in areas with low temperature.

An experiment was carried out at ICIMOD's Demonstration and Training Centre to test, select, and demonstrate various nitrogen-fixing trees and shrubs with the main objective of selecting appropriate species to establish hedgerows in the middle hills of Nepal and other areas of the HKH with similar climatic conditions. The trials started in 1993 and the bulk of the results were obtained in the ensuing seven years. A total of 21 nitrogen-fixing plant species from various origins (plus three of the same species from different origins) were tested. They were assessed for nursery germination rate, seed weight, mortality rate, height growth, base girth growth, branching characteristics, and biomass production. The germination rate in the nursery varied from 3 to 98%; there was no direct relationship between seed weight and germination rate. Twelve species that showed good germination and emergence at the plant nursery were planted as hedgerows. The remaining species were excluded from the trial as a result of very poor germination or very poor growth or for other reasons; a few of the excluded species were planted separately as non-hedgerow plants to test whether they would in fact grow.

Of the 12 species used to plant hedgerows, five died completely during the trials, five almost died, and five survived: *Alnus nepalensis*, *Flemingia macrophylla*, *Albizia lebbeck*, *Indigofera dosua,* and *Desmodium floribundum*. The average mortality rates over all sites and years were fairly similar for the five surviving species, ranging from 31.4% for *Albizia lebbeck* to 39.6% for *Indigofera dosua.* All the five species that survived the trials are indigenous species, although the *Flemingia macrophylla* seeds were obtained from the Philippines. After initial failure, a further hedgerow of *Leucaena leucocephala* was planted to reassess suitability; it has survived and performed satisfactorily but was not included in the detailed trials. This species is an introduced but already domesticated species. All the directly introduced species failed. *Alnus nepalensis* had the highest growth rate and biomass production and *Desmodium floribundum* the lowest.

Five species are recommended as hedgerow species for Godavari and other areas with similar climate and soils on the basis of selection criteria related to habit (tree, shrub, herbaceous), growth rate, coppicing capacity, ability to fix nitrogen, suitability to local conditions, ease of reproduction, and rooting character; these are, in order

of recommendation, *Flemingia macrophylla, Leucaena leucocephala, Indigofera dosua, Alnus nepalensis,* and *Albizia lebbeck*. Most of the species used to establish hedgerows in tropical areas, including *Calliandra calothyrsus*, *Cassia siamea*, *Desmodium rensonii*, and *Gliricida sepium*, are not suited to the mid hills climate. Although *Alnus nepalensis* was the species used to establish most hedgerows at Godavari, it is not recommended for use if there are other species available because of the high cost of establishing hedgerows and its susceptibility to insect herbivores. Testing of further species suitable for cooler climates is needed.

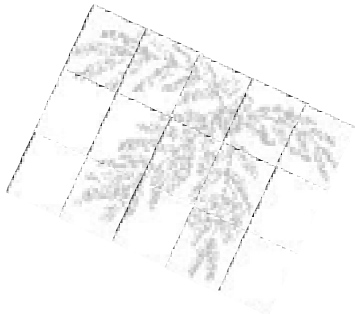
Acknowledgements

The authors would like to thank Mr. Jivan Tamang for the collection of the field data. The Governments of China, Nepal, and Pakistan generously provided most of the trees, shrubs, and other plants tested at the Demonstration and Training Centre. The financial support from various donors, especially the Asian Development Bank, for most of the research and activities carried out at the site is gratefully acknowledged.

Acronyms and Abbreviations

ADB	Asian Development Bank
ATSCFS	Appropriate Technologies for Soil Conserving Farming Systems
ICIMOD	International Centre for Integrated Mountain Development
CHIAT	contour hedgerow intercropping agroforestry technology
HKH	Hindu Kush-Himalayas
SALT	sloping agricultural land technology

Contents



Performance and Selection of Nitrogen-Fixing Hedgerow Species

Introduction

Sloping agricultural land technology (SALT), also known as 'contour hedgerow intercropping (agroforestry) technology (CHIAT)' or 'alley cropping', is an agroforestry practice designed to enable permanent farming of sloping cropland on a sustainable basis. Essentially it consists of planting hedgerows of nitrogen-fixing species along the contour lines of sloping land at intervals of approximately 4-5 metres. The hedgerows create a living barrier that traps sediments. With time, as the sediments build up behind the hedges, the area between the hedgerows develops into a flat alley suitable for growing crops. Soil fertility is maintained by direct input to the soil of nitrogen from plant biomass, that is decomposed roots and nodules and hedgerow clippings which are dug into the soil. The hedgerows stabilise the slopes, prevent soil loss, and help conserve soil moisture. The practice is described in detail in Partap and Watson (1994) and Tang Ya (1999a) among others. Originally developed for tropical areas, the practice has shown a great potential for controlling soil erosion and improving land productivity in the Hindu Kush-Himalayan (HKH) region (Tang Ya 1998; Tang Ya et al. 2001, 2002) and has received considerable attention from researchers and development workers in recent years. The form of the technology called alley cropping has been studied both intensively and extensively in the humid tropics (e.g., Kang et al. 1990; Kang 1993; Kiepe 1995). This method is used mainly on cropland with a gentle slope, or even flat land, with the main aim of improving soil fertility and providing fodder. In contrast, SALT or CHIAT is mainly applied to cropland with steep slopes, with the prime objective of reducing soil erosion (Palmer 1996).

Although many plant species can be used to establish hedgerows, nitrogen-fixing plants are recommended for most areas because they can grow in very poor soil, they grow fast, and they produce high quality fodder, as well as contributing directly to improving soil fertility in the alleys. The hedgerows must be very thick to function effectively as soil erosion barriers. They are pruned regularly to reduce shading of the companion crops and to provide fresh biomass to improve soil fertility and/or fresh fodder. Selection of appropriate species for the hedgerows is a key factor in the successful establishment of a contour hedgerow intercropping system. Until now, however, most research on alley cropping or contour hedgerow intercropping has focused on a limited number of species, and most species selection studies have been aimed at tropical areas with only a few studies in subtropical areas (ICIMOD 1999). Information about species suitable for cooler regions is particularly lacking and there are few reports of systematic comparisons of large numbers of species for use in this system under different environmental conditions.

The Hindu Kush-Himalayan region covers a vast area and the biophysical conditions vary greatly within the region. With financial support from the Asian Development

Bank (ADB), the International Centre for Integrated Mountain Development (ICIMOD) implemented a two-phase project on 'Appropriate Technologies for Soil Conserving Farming Systems' (ATSCFS) in six of ICIMOD's eight member countries (Bangladesh, China, India, Myanmar [first phase only] and Nepal and Pakistan) from 1994 to 2001. The prime objective of the project was to develop and test suitable models of contour hedgerow intercropping technology that can support sustainable production of cropland in different parts of the HKH region. The results indicated that the technology can be applied successfully in the region if appropriate species are used to establish hedgerows and hedgerows are properly managed, but that the number of species that are appropriate is limited (Tang Ya 1998; ICIMOD 1999, 2001). Because most of the research and development work has been conducted in the tropics, there is limited information available on species suitable for use in other climates. Screening and selection of nitrogen-fixing trees or shrubs to determine the best adapted species for the specific environments with their diverse biophysical conditions in the HKH region has thus become a pressing issue.

The goal of species selection for a hedgerow system is to put the right species in the right place. As a part of the ATSCFS project, an experiment was carried out at ICIMOD's Demonstration and Training Centre at Godavari from 1993 to 2001 to test different nitrogen-fixing species and select plants suitable for establishing contour hedgerow systems in the subtropical to temperate conditions of the mid hills of Nepal and in other areas in the HKH region with similar agro-ecological conditions. The results of the tests for screening and selection of appropriate nitrogen-fixing plants are described in detail in the following.

Materials and Methods

Site characterisation

The ICIMOD Demonstration and Training Centre is located at Godavari, in the southeast corner of the Kathmandu valley, some 15 km from ICIMOD's headquarters in Kathmandu, Nepal. When ICIMOD was presented with the site in 1993, it was an area of heavily degraded bushland with a few trees of little economic importance. The site had never been cultivated. Parts of the site were cleared manually for various development activities. The detailed physical and biological characteristics of the site are described together with the history and present day activities in the first book in this series (Tang Ya 2004). The relevant biophysical characteristics are summarised briefly in Table 1. The mean monthly temperatures and rainfall in the period 1996-2001 are shown in Table 2.

In its original state, the site was regarded as something of a 'green desert' because 70% of the natural species of bushes and trees that were left were economically less useful. The clay loam soils are rich in organic matter and total nitrogen, with relatively high available potassium and low available phosphorous. The climate is subtropical monsoon with a mean annual temperature from 1996 to 2001 of 15.9°C and a mean annual rainfall of 2062 mm, some 80% of which fell between June and September. Frost occurs from December to February. The natural vegetation type is mixed deciduous and evergreen broadleaved forest dominated mainly by species of the families Fagaceae, Theaceae, Lauraceae, and Betulaceae.

Table 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
Temperature (1996-2001)	
• 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

Table 2: Monthly temperature (°C) and rainfall (mm) 1996-2001

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual mean
Temperature	7.6	10.2	14.6	18.3	20.3	21.0	20.8	20.5	19.4	16.5	12.9	8.9	15.9
Rainfall	17.5	15.1	33.1	72.7	148.5	378.8	556.2	513.9	212.7	79.7	6.8	27.3	2062

Selection of test species

Except in the high altitude purely pastoral areas, farmers in the mountain and hill areas of the HKH region mostly practice a form of mixed crop-livestock farming based on agroforestry practices and multiple use of species and land. If farmers are to accept SALT as a valuable approach to conserving and exploiting the small parcels of land that are available, the species used for hedgerows must fit with this concept. For this reason, various woody plant species that have potential as hedgerow species were tested at the site.

Table 3 shows the complete list of leguminous and non-leguminous species tested, together with their origin and the plant family they belong to. The main criteria for selection were that the plants were nitrogen fixing and fast growing, as shown from our own experience or other's work. Some, like *Acacia dealbata* and *Acacia mearnsii*, were chosen because their leaf litter was already used by local communities to improve soil fertility; some, like *Alnus nepalensis,* because they have been used in some parts of the HKH region for soil improvement for a long time; and some, like *Calliandra calothyrsus, Leucaena leucocephala, Flemingia macrophylla* and *Tephrosia candida* because they had proven to be satisfactory hedgerow plants in other areas. Most of the plants chosen are pioneer plants in poor soils, another useful characteristic.

A preliminary germination test was used to select plant species for the hedgerow trials (see below). Only species that showed good germination and emergence at the plant nursery were used in the advanced trials, a total of twelve of the 24 species tested: *Albizia lebbeck*, *Albizia procera, Alnus nepalensis*, *Amorpha fruticosa*, *Crotalaria cytisoides, Dalbergia sissoo*, *Desmodium rensonii*, *Desmodium floribundum*, *Flemingia macrophylla*, *Indigofera dosua*, *Leucaena leucocephala*, and *Tephrosia candida*. The remaining nitrogen-fixing species were excluded from the hedgerow trial as a result of very poor germination or very poor growth or for other reasons; a few of the excluded species were planted separately to test performance.

Table 3: Potential hedgerow plant species tested at Godavari

Botanic Name	Origin	Family-subfamily
Legumes		
Acacia auriculaeformis	Yunnan, China	Leguminosae-Mimosoideae
Acacia dealbata	Yunnan, China	Leguminosae-Mimosoideae
Acacia mearnsii	Yunnan, China	Leguminosae-Mimosoideae
Acacia villosa	Myanmar	Leguminosae-Mimosoideae
**Albizia lebbeck*	Nepal	Leguminosae-Mimosoideae
**Albizia procera*	Nepal	Leguminosae-Mimosoideae
**Amorpha fruticosa*	Pakistan	Leguminosae-Papilionoideae
Caesalplinia sappan	Davao, Philippines	Leguminosae-Caesalpinioideae
Calliandra calothyrsus	Davao, Philippines	Leguminosae-Papilionoideae
Cassia siamea	Yunnan, China	Leguminosae-Papilionoideae
**Crotalaria cytisoides*	Nepal	Leguminosae-Papilionoideae
**Dalbergia sissoo*	Nepal	Leguminosae-Papilionoideae
**Desmodium floribundum*	Nepal	Leguminosae-Papilionoideae
**Desmodium rensonii*	Davao, Philippines	Leguminosae-Papilionoideae
**Flemingia macrophylla*	Davao, Philippines	Leguminosae-Papilionoideae
**Flemingia macrophylla*	Nepal	Leguminosae-Papilionoideae
Indigofera anil	Davao, Philippines	Leguminosae-Papilionoideae
**Indigofera dosua*	Nepal	Leguminosae-Papilionoideae
Leucaena diversifolia	Davao, Philippines	Leguminosae-Mimosoideae
**Leucaena leucocephala*	Davao, Philippines	Leguminosae-Mimosoideae
**Leucaena leucocephala*	Nepal	Leguminosae-Mimosoideae
**Leucaena leucocephala*	China	Leguminosae-Mimosoideae
**Robinia pseudoacacia*	Pakistan	Leguminosae-Papilionoideae
Robinia pseudoacacia	Nepal	Leguminosae-Papilionoideae
**Tephrosia candida*	Sichuan, China	Leguminosae-Papilionoideae
Non-leguminous nitrogen-fixing		
**Alnus nepalensis*	Nepal	Betulaceae

* Species selected for advanced trials

Methods

Planting of hedgerows

Most of the species were introduced from ICIMOD member countries or the southern Philippines (Table 3); thus it was necessary to test their performance (as hedgerows) and survival under the conditions that prevail in the Nepali mid-hills. All the species were grown from seed except for *Dalbergia sissoo*, which was grown from stem cuttings. Seeds of three species, *Flemingia macrophylla*, *Leucaena leucocephala*, and *Robinia pseudoacacia*, were obtained from more than one origin.

A plant nursery was established in the lower part of the ICIMOD site. The weight of 100 seeds of each species was determined and the seed germination rate tested at the nursery. Germination rate is an important indicator and is used to determine seeding density. Successful seedlings were raised in the nursery and transplanted to form hedgerows.

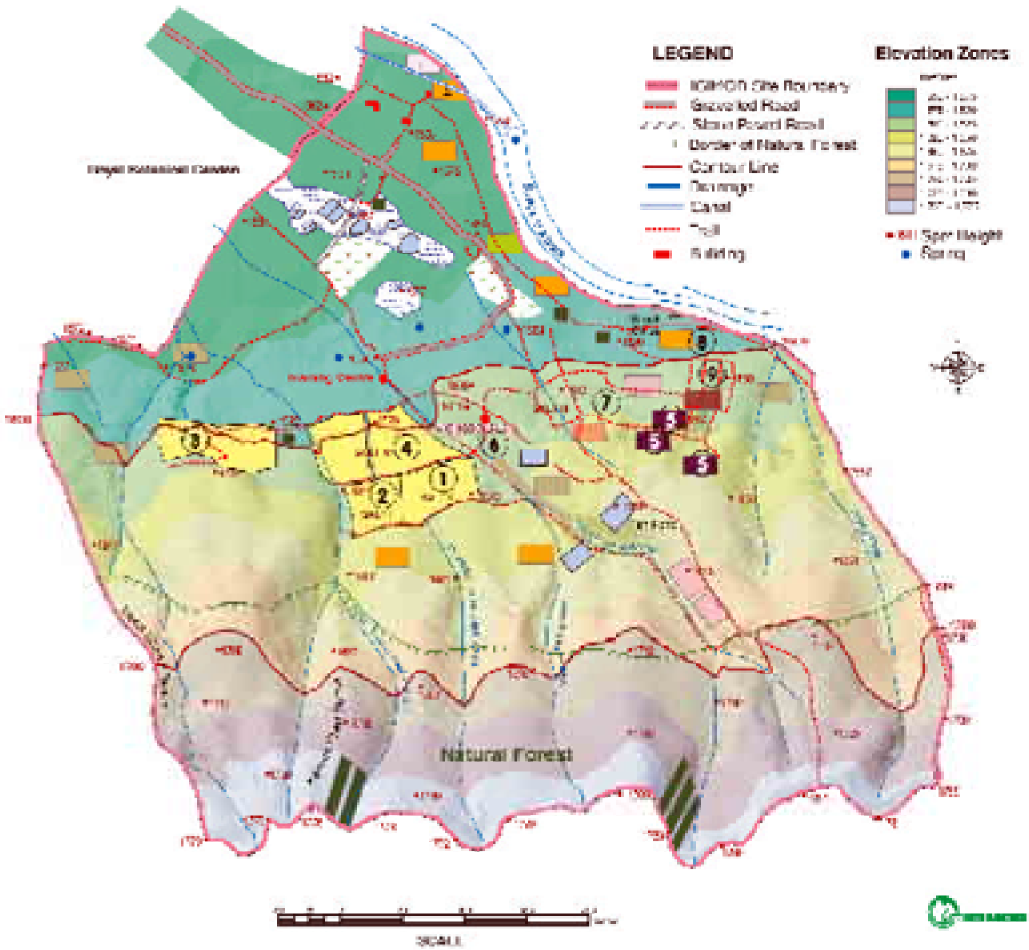
In view of the potential impact of slope gradient and other site factors on survival and growth of plants, the potential hedgerow plant species were planted at nine different sites within the Godavari site. Some of these sites were used for other related trials and experiments, as is apparent from their names. The results of these experiments are reported in other volumes in this series. The sites are listed below, their position is shown in Figure 1.

- Site 1: SALT 1
- Site 2: SALT 2
- Site 3: SALT 3
- Site 4: SALT 4
- Site 5: Soil erosion plots (five treatments with three replicates)
- Site 6: ICIMOD Point
- Site 7: Species performance trial
- Site 8: Nepal citrus trial
- Site 9: Nitrogen-fixing hedgerows species variation trial

Initial planting was carried out during the monsoon period in 1993, 1994, and 1995. Double hedgerows were planted, i.e., two lines of plants forming one hedgerow. In some cases two species were planted in a single hedgerow line in early trials, but this did not show a particular advantage. The assessments below always relate to single species. The site, date of planting, and total length of the hedgerows are shown in Table 4. Except for those species that showed complete mortality in the first year, dead plants were replaced with seedlings of the same species during the monsoon period of the following year to maintain the planting density of the initial design.

Measurements

Good hedgerow species should have a low mortality rate in order to ensure the desired stand density and to reduce the cost of replanting or filling in gaps caused by mortality. The number of plants that had died was recorded for each species and site each year for five years to determine the mortality rate.



Sites of the species trials

① Site 1: SALT 1

② Site 2: SALT 2

③ Site 3: SALT 3

④ Site 4: SALT 4

⑤ Site 5: Soil erosion plots (five treatments with three replicates)

⑥ Site 6: ICIMOD Point

⑦ Site 7: Species performance trial

⑧ Site 8: Nepal citrus trial

⑨ Site 9: Nitrogen-fixing hedgerows species variation trial

Data source: ICIMOD Field Survey, Map: ICIMOD, IKM MENRIS 2004

Figure 1: Map of the ICIMOD Demonstration and Training Centre site at Godavari showing the position of the plots used in the species trials

Table 4: Species, date of planting, and length of hedgerows at different sites

Site	Species	Date of initial planting	Total length (m)*
Site 1	*Alnus nepalensis*	21/7/1994	160
	Albizia lebbeck	21/7/1994	160
	Indigofera dosua	21/7/1994	90
	Flemingia macrophylla	21/7/1994	100
Site 2	*Alnus nepalensis*	26/7/1994	160
	Albizia lebbeck	26/7/1994	160
	Indigofera dosua	26/7/1994	90
	Flemingia macrophylla	26/7/1994	100
Site 3	*Alnus nepalensis*	8/7/1994	103
	Indigofera dosua	6/7/1994	271
	Flemingia macrophylla	6/7/1994	87
	Leucaena leucocephala	25/9/1993	332
	Desmodium rensonii	23/9/1993	34
	Desmodium floribundum	25/9/1993	88
Site 4	*Alnus nepalensis*	10/6/1993	504
	Albizia lebbeck	5/6/1993	204
	Indigofera dosua	22/6/1993	121
	Flemingia macrophylla	12/6/1994	313
	Desmodium floribundum	5/7/1993	180
	Tephrosia candida	1/7/1993	113
	Albizia procera	9/7/1993	65
	Dalbergia sissoo	9/7/1993	65
Site 5	*Alnus nepalensis*	22/6/1995	405
	Indigofera dosua	22/6/1995	135
Site 6	*Alnus nepalensis*	16/7/1993	413
	Albizia lebbeck	13/7/1993	509
	Indigofera dosua	7/7/1993	174
	Flemingia macrophylla	7/7/1993	107
	Tephrosia candida	7/7/1993	141
Site 7	*Alnus nepalensis*	21/5/1994	89
	Indigofera dosua	25/7/1993	139
	Flemingia macrophylla	25/7/1993	703
	Desmodium rensonii	25/7/1993	113
	Desmodium floribundum	7/7/1993	76
	Tephrosia candida	9/6/1993	50
	Amorpha fruticosa	25/7/1993	61
Site 8	*Alnus nepalensis*	25/9/1993	166
	Indigofera dosua	23/5/1994	31
	Flemingia macrophylla	27/9/1993	241
	Amorpha fruticosa	25/5/1994	51
Site 9	*Indigofera dosua*	17/6/1995	185
	Flemingia macrophylla	16/6/1995	1376
	Leucaena leucocephala	22/6/1995	129
	Desmodium rensonii	24/6/1995	10
	Desmodium floribundum	28/6/1995	50
	Crotalaria cytisoides	28/6/1995	76

* length of all lines of single hedgerows (twice length of double hedgerows) at one site added together

Ten plants of each of the species selected for the hedgerow trials and of two further promising species (*Robinia pseudoacacia* and *Acacia mearnsii*) were allowed to grow without pruning to observe the overall growth rate. Height, diameter 10 cm above the ground, and number of branches were measured annually.

Pruning was carried out once, twice, or three times per year depending on the growth, and the total average annual fresh biomass production determined for each potential hedgerow species at each site.

Crops and fruit trees were planted in the cropping season in the alleys separated by the hedgerows. The growth and yield of fruit trees are described in book No.5 in this series (Tang Ya and Thapa [in preparation]).

RESULTS

Germination and emergence

The weight of 100 seeds and germination rate of the tested species are shown in Table 5.

Table 5: Nursery germination rate and seed weight of various species

Plant names	Seed weight/100 pc g	Germination rate %	Seedlings per unit seed weight (g)	Remarks
**Desmodium rensonii*	2.20	98.0	45	
**Desmodium floribundum*	0.24	95.0	396	
**Leucaena leucocephala*	7.00	90.0	13	From Nepal
**Flemingia macrophylla*	2.02	85.0	42	From Philippines
**Flemingia macrophylla*	1.80	80.0	44	From Nepal
**Indigofera dosua*	1.02	72.5	71	
Leucaena diversifolia	1.20	70.0	58	
**Crotalaria cytisoides*	2.40	60.0	25	
**Albizia procera*	3.26	56.0	17	
Calliandra calothyrsus	5.00	55.0	11	
**Albizia lebbeck*	0.31	50.0	161	
Tephrosia candida	2.30	48.0	21	
Robinia pseudoacacia	2.12	35.0	17	From Nepal
**Robinia pseudoacacia*	2.12	34.0	16	From Pakistan
Caesalplinia sappan	6.57	30.0	5	
**Leucaena leucocephala*	6.00	30.0	5	From the Philippines
Acacia villosa	1.39	26.2	19	
**Alnus nepalensis*	0.07	25.0	357	
Acacia dealbata	1.90	20.0	11	
**Amorpha fruticosa*	0.93	10.0	11	
Acacia auriculaeformis	2.50	5.0	2	
Acacia mearnsii	1.40	5.0	4	
Cassia siamea	2.14	3.0	1	
**Dalbergia sissoo*	NA	NA		

*Species selected for advanced trials

The germination rate varied from 3 to 98%. Two species of *Desmodium* had the highest germination rate (98% for the introduced *Desmodium rensonii* and 95% for the local *Desmodium floribundum)* and *Cassia siamea* (3%) the lowest rate. Only seven of the species tested had a germination rate over 70%; four had a germination rate between 50 and 60%. The seeds of *Alnus nepalensis* are very small and were the lightest of those tested. Although the germination rate was low, the number of seedlings per unit seed weight was the second highest of all the species. Unfortunately the seed viability of *Alnus nepalensis* drops rapidly after harvesting; this may have been the main contributing factor to the low germination rate.

Caesalpinia sappan, *Calliandra calothyrsus,* and *Cassia siamea* did not emerge at all, although the first two species had germination rates of 30% and 55%, respectively. Low temperature may have contributed to the failure as all three are essentially tropical species. Although *Calliandra calothyrsus* and *Cassia siamea* are important hedgerow species in other regions, it seems they cannot survive the low temperatures typical of the Nepali mid-hill areas. All four species of *Acacia* had low germination rates and were not included in the advanced trials. Some *Leucaena diversifolia* plants were planted in the plant nursery but growth was not as promising as for *Leucaena leucocephala* and it was not included in the advanced trials despite its good germination result. About 15m of hedgerows were planted with *Robinia pseudoacacia,* but growth was poor and all plants died back within four years, thus it was also excluded from the advanced trials.

The majority of the tested species had a seed weight of between 1.0 and 2.5g per 100 seeds. *Leucaena leucocephala* and *Caesalpinia sappan* had the highest seed weights and *Alnus nepalensis* the lowest. In general, large seeds are expected to have a better seed germination rate than smaller seeds but in the present test the germination rate did not correlate with seed weight.

Four of the six species with germination rates of 70% or more have been used widely to establish hedgerows in tropical Africa and Asia: *Leucaena leucocephala* and *Leucaena diversifolia* are probably the most widely used species in hedgerow intercropping systems; *Desmodium rensonii* has been used in the Southern Philippines for the past three decades (Palmer 1996); and *Flemingia macrophylla* is widely used in tropical Africa and Asia and there might be wild plants in Nepal. *Desmodium floribundum* and *Indigofera dosua are* local shrub species and until now have not been used elsewhere in a hedgerow intercropping system.

Mortality

Of the 12 species used to plant hedgerows, five died completely during the trials, five almost died, and five survived. *Desmodium rensonii* died completely within one year of planting; all the *Dalbergia sissoo* and *Albizia procera* plants died after three years; and *Amorpha fruticosa* and *Crotalaria cytosoides* died in February 1998 (after four and a half years). Furthermore, all *Tephrosia candida* plants at sites 1 and 2 and two-thirds of the plants at Site 6 died in the first year; and, despite replanting, all other *Tephrosia candida* plants had died by the end of the trial except for a few at site 4, which died shortly after the trial ended. Similarly all the *Leucaena leucocephala* plants (seed from the Philippines) died in the year after transplanting. However, in view of the wide use of this species for hedgerows in other regions, and its proven success in subtropical areas of China, another hedgerow of *Leucaena leucocephala* (seed from China) about 10m long was established at site 6 (ICIMOD point) for further assessment of suitability. The replanted *Leucaena leucocephala* has survived and performed satisfactorily, but it was not included in the trials and no annual measurements were made.

Various causes were suggested for the failure of some promising species to survive. One is temperature. *Desmodium rensonii* died within a year of planting at Godavari and survived for a maximum of five years at another ATSCFS project site at Mugling in southern Nepal, where both the mean annual temperature and annual rainfall are considerably higher than at Godavari. It is a tropical species and clearly unsuited to cooler sub-tropical conditions. Another cause of death appeared to be sensitivity to pruning. The *Amorpha fruticosa* and *Crotalaria cytosoides* plants in the hedgerow trials all died by 1998, but other plants of these species kept without pruning for the growth trials survived to at least 2000 *(Crotalaria cytosoides)*, and unpruned plants of *Amorpha fruticosa* are still growing well in 2004. *Tephrosia candida* also appeared to die back in response to pruning with pruning height playing an important role: the plants that survived to 1998 at site 4 were mistakenly pruned to a height of 70-80 cm instead of 50 cm, but died subsequently after pruning to 50 cm.

A few species that were not included in the advanced species selection trials were planted as non-hedgerow plants at the site to test whether they would in fact grow. Three of these species – *Caesaplinia sappan, Cassia siamea,* and *Calliandra calothyrsea* – failed completely, reflecting their exclusively tropical origin. More surprisingly, *Robinia pseudoacacia* (Pakistan) survived for only three years although it can grow widely. The causes of its dieback, and the conditions under which it can survive, should be explored because it might be a good hedgerow species in cool and dry areas, for which there are fewer potential hedgerow species. It was equally unclear why *Acacia mearnsii* failed to thrive as it can grow well in areas such as Kunming in Yunnan, China, and Almora, in Uttaranchal, India, which have a similar mean monthly temperature, general climate, and soil to Godavari. This species and another very closely related one, *Acacia dealbata*, have been used to form hedgerows in some places in China, and other countries and are good timber and fuelwood species in dry areas and areas similar to Godavari, thus further tests into the cause of mortality and favourable conditions for survival could be useful.

Six species survived when planted as hedgerows: *Alnus nepalensis*, *Flemingia macrophylla*, *Albizia lebbeck*, *Indigofera dosua,* and *Desmodium floribundum* in the hedgerow trials, and *Leucaena leucocephala* grown later from Chinese seed as a separate hedgerow. The average mortality rates over all sites and years for the five species in the trials are shown in Table 6. They were fairly similar for all species, ranging from 31.4% for *Albizia lebbeck* to 39.6% for *Indigofera dosua.* All the five species that survived the trials are indigenous species, although the *Flemingia macrophylla* seeds were obtained from the Philippines; the sixth species, *Leucaena leucocephala,* is an introduced but already domesticated species. All the directly introduced species failed.

There was an apparent tendency at each site for the mortality rate to increase with time. This probably reflects the management of the experiment rather than a real trend. According to the experimental protocol, any dead plants were replaced with the same number of seedlings. The replanted seedlings were shaded and crowded by the remaining taller plants and at a disadvantage in competition for other resources. Thus the number of plants that died increased each year as it included both replanted seedlings and weaker mature plants that were crowded out. Replacing dead plants one for one was a purely experimental protocol, designed to maintain the original plant density (not taking into account the increase in size of individual plants). It is neither practical nor usual practice on farmers' land. At other ATSCFS project sites, gaps were identified and filled only one or two times during the experiment to maintain foliage density rather than numerical density. This was the approach used, for example, in Ningnan, China, where hedgerow establishment was

Table 6: Mortality rate of different species (%)								
	Number of plants	1993	1994	1995	1996	1997	1998	Average
Alnus nepalensis								
Site 1	3300		4.7	24.7	21.7	30.2	66.8	29.6
Site 2	3300		5.6	36.6	18.2	24.2	65.1	29.9
Site 3	886	22.6	20.1	21.3	24.3	40.1	51.1	29.9
Site 4	2075		6.8	8.6	38.6	48.0	69.7	34.3
Site 5	4050			4.7	40.9	56.7	85.2	41.2
Site 6	2517		4.8	4.6	24.3	28.5	49.4	22.3
Site 7	958		47.0	10.1	26.7	51.1	82.3	43.4
Site 8	1331	10.9	6.4	7.5	58.7	70.6	91.3	40.9
Average		16.8	13.6	14.8	31.7	43.7	70.1	34.0
Albizia lebbeck								
Site 1	1800		5.5	7.6	11.7	50.3	65.5	28.1
Site 2	1800		5.6	5.5	6.4	59.0	70.1	29.3
Site 4	2705	7.6	11.6	18.6	29.9	51.8	69.7	31.5
Site 6	2546	7.7	12.8	26.7	47.1	58.9	66.3	36.6
Average		7.7	8.9	14.6	23.8	55.0	67.9	31.4
Indigofera dosua								
Site 1	1800		6.2	17.0	51.3	69.1	86.8	46.1
Site 2	1800		5.2	11.9	45.0	64.2	86.1	42.5
Site 3	1836		17.0	21.9	32.7	50.7	63.8	37.2
Site 4	2974	3.8	8.2	17.9	33.5	45.5	69.7	29.8
Site 5	1350		3.3	7.0	41.4	67.4	88.3	41.5
Site 6	1646	5.8	6.2	12.8	31.2	50.5	74.4	30.2
Site 7	999	5.1	9.6	20.5	29.5	61.6	80.3	34.4
Site 8	190		29.5	24.2	30.0	52.6	72.1	41.7
Site 9	1719		18.5	29.2	57.7	70.7	89.2	53.1
Average		4.9	11.5	18.0	39.1	59.1	79.0	39.6
Flemingia macrophylla								
Site 1	2000		10.6	25.5	16.2	60.4	75.1	37.6
Site 2	2000		8.0	20.6	35.6	60.9	72.5	39.5
Site 3	565	11.2	15.0	20.2	36.3	45.3	67.6	32.6
Site 4	2849	4.0	11.2	21.1	32.9	42.6	54.5	27.7
Site 6	2517	4.0	12.8	23.6	38.3	40.2	49.5	28.1
Site 7	5431	9.2	16.4	30.2	45.7	57.6	76.0	39.2
Site 8	1604	3.7	12.6	25.8	44.3	63.3	77.7	37.9
Site 9	5667			33.7	46.2	62.2	77.3	54.9
Average		6.4	12.4	25.1	36.9	54.1	68.8	37.2
Desmodium floribundum								
Site 3	599	6.7	12.5	20.0	26.5	52.1	89.1	34.5
Site 4	1306	4.0	6.7	10.2	33.8	48.4	78.0	30.2
Site 6	740	5.3	6.8	13.1	28.9	49.5	89.0	32.1
Site 9	827	3.9	8.1	13.1	34.5	38.5	92.3	31.7
Average		5.0	8.5	14.1	30.9	47.1	87.1	32.1

most successful. In the Godavari trials, the actual hedgerows formed by the plants were still very effective in controlling soil erosion indicating that the apparently high rates of mortality were not related to reduced hedgerow function; no washed out soil was observed immediately below these sites.

In practice it should not be necessary to replace many plants in the hedgerows. In order to evaluate hedgerows without replanting, replacement of dead plants was stopped in the trials in 2000. It would be useful in the future to assess the extent of any gaps in the hedgerows and whether the remaining plants are sufficient to form an acceptable hedgerow and act as soil erosion barriers. This would provide further information about the long-term suitability of different species.

The mortality for all the hedgerow species was highest in 1998. This was probably related to climatic conditions; the lowest air temperature during the experiment was observed in February 1998, which might have contributed to dieback of many plants, and there was also an exceptionally strong rainfall event in April 1998 which may have led to soil loss and root exposure (Tang Ya and Nakarmi 2004).

The growth pattern of the same species at different sites differed markedly, which probably reflected differences in slope and aspect, as well as other topographical features and physical properties. It is well-known, for example, that temperature, rainfall, soil, soil moisture, solar radiation, and vegetation are affected by the aspect.

Growth rate

Ten plants each of the species selected for hedgerow trials, and of two further promising species (*Robinia pseudoacacia* and *Acacia mearnsii*) were maintained at random in the hedgerows or at sites close by without pruning in order to monitor growth and other related characteristics. The height, diameter at 10 cm above ground, and number of branches were measured annually in October at the end of the growing season. The results (average of measurements for the ten plants per species) are shown in Tables 7-9 and Figures 2-4.

Growth in height

The growth in height is shown in Table 7 and Figure 2 (surviving hedgerow species only.) As in the actual hedgerow trials, *Desmodium rensonii*, *Dalbergia sissoo*, *Albizia procera,* and *Tephrosia candida* all died during the trials; in contrast to the hedgerow trials, unpruned *Amorpha fruticosa and Crotalaria cytisoides* continued to flourish, but the *Crotalaria cytisoides* plants died after pruning in 2000.

Alnus nepalensis grew fastest reaching a height of about 14m after five years and over 16m after seven years (Figure 2). *Desmodium floribundum, Flemingia macrophylla*, and *Indigofera dosua* reached their maximum height of around 4m after 5-6 years. *Amorpha fruticosa* and *Albizia lebbeck* were still growing slowly at the end of the trial: *Albizia lebbeck* had reached a height of 6m and *Amorpha fruticosa* a height of 3m. *Alnus nepalensis* and *Albizia lebbeck* are tree species, whereas the remaining four species are shrubs.

Table 7: Height (cm) of selected plant species

	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Alnus nepalensis	15.5	356.6	445.3	711.3	928.0	1375.0	1572.0	1615.0	1627.0	1638.0	1642.8
Albizia lebbeck	18.5	184.1	246.7	310.0	415.0	505.0	552.0	595.0	615.0	623.0	624.3
Indigofera dosua	20.5	149.8	174.3	250.0	360.0	382.0	409.0	410.1	412.0	413.0	414.5
Flemingia macrophylla	19.0	196.0	247.9	309.5	319.0	386.0	402.0	403.8	405.0	407.0	407.6
Desmodium floribundum	15.5	125.0	180.4	205.0	390.0	398.0	416.0	417.3	419.0	421.0	421.7
Amorpha fruticosa	15.5	130.3	145.3	170.2	192.3	215.0	260.0	286.0	302.0	308.0	308.9
Crotalaria cytisoides	-	-	43	186.0	372.0	402.0	435.0	435.6	Complete mortality		
Tephrosia candida	17.5	180.3	193	260.0	310.5	Complete mortality					
Albizia procera	55.0	128.4	215.3	300.0	Complete mortality						
Dalbergia sissoo	20.0	52.0	199.2	270.0	Complete mortality						
Robinia pseudoacacia	0.0	26.0	82.6	260.0	Complete mortality						
Desmodium rensonii	10.0	245.0	Complete mortality								
Acacia mearnsii	12.5	86.7	Complete mortality								
Leucaena leucocephala	15.5	42.3	Complete mortality								

Table 8: Diameter at base of selected plant species (cm)

	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Alnus nepalensis	0.35	3.49	6.72	9.78	14.42	18.32	21.69	23.40	25.60	26.70	27.30
Albizia lebbeck	0.41	2.40	5.12	6.53	7.92	9.20	10.83	11.50	12.50	13.80	14.10
Indigofera dosua	0.52	1.56	2.12	3.21	4.23	5.26	6.18	6.30	6.80	7.40	7.63
Flemingia macrophylla	0.38	1.82	2.02	2.56	3.25	5.56	6.38	7.30	7.80	8.60	8.95
Desmodium floribundum	0.55	1.66	2.13	2.74	3.65	5.56	6.98	7.10	7.60	8.20	8.32
Amorpha fruticosa	0.31	1.30	1.96	2.12	3.20	5.20	6.96	7.30	7.60	8.10	8.25
Crotalaria cytisoides	-	-	0.60	1.90	2.72	4.22	6.15	6.30	Complete mortality		
Tephrosia candida	0.41	1.53	3.36	4.43	5.22	Complete mortality					
Albizia procera	0.90	2.90	4.10	5.51	Complete mortality						
Dalbergia sissoo	0.65	1.15	1.94	2.52	Complete mortality						
Robinia pseudoacacia	0.00	0.60	1.82	2.27	Complete mortality						
Desmodium rensonii	0.30	1.53	Complete mortality								
Acacia mearnsii	0.31	0.76	Complete mortality								
Leucaena leucocephala	0.35	0.99	Complete mortality								

Table 9: Number of branches of selected plant species

Species	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Alnus nepalensis	18	23	29	37	45	52	56	61	68	73
Albizia lebbeck	20	25	28	61	69	77	81	86	87	91
Indigofera dosua	14	19	24	32	38	47	51	55	57	63
Flemingia macrophylla	14	18	23	28	32	43	55	57	61	69
Desmodium floribundum	22	27	33	45	52	59	62	65	68	76
Amorpha fruticosa	9	10	14	18	24	33	36	39	43	48
Crotalaria cytisoides	-	-	9	23	29	36	39	Complete mortality		
Tephrosia candida	10	13	19	24	Complete mortality					
Albizia procera	2	3	5	Complete mortality						
Dalbergia sissoo	9	10	12	Complete mortality						
Robinia pseudoacacia	2	3	6	Complete mortality						
Desmodium rensonii	21	Complete mortality								
Acacia mearnsii	8	Complete mortality								
Leucaena leucocephala	7	Complete mortality								

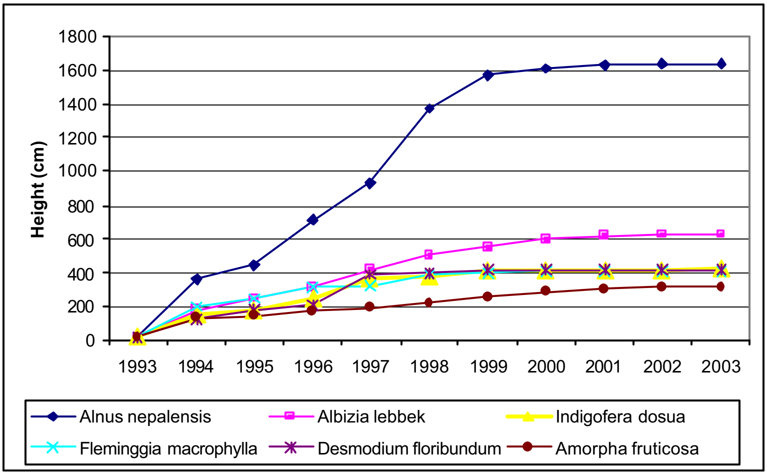


Figure 2: Height growth of selected species

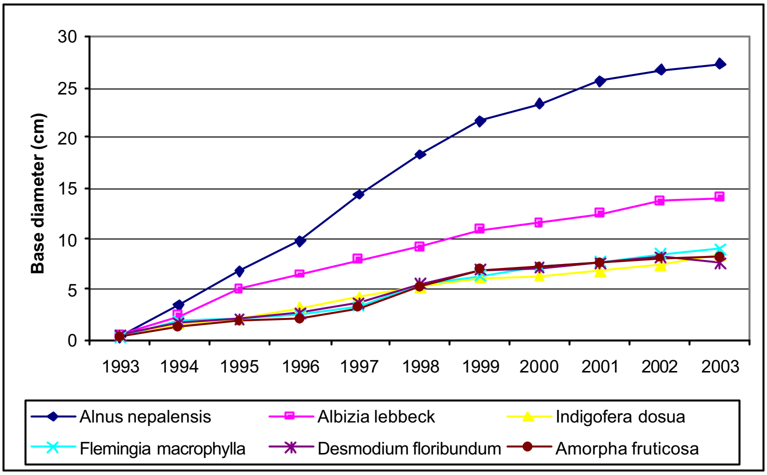


Figure 3: Base girth growth of selected species

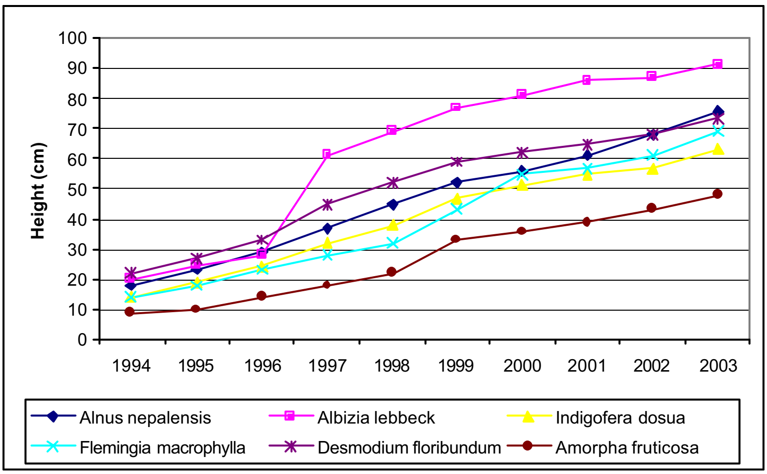


Figure 4: Branching feature of potential hedgerow species

Only seven of the species grown without pruning survived five years and one of these died soon after. The height growth data suggest that *Albizia lebbeck*, *Alnus nepalensis*, *Desmodium floribundum, Flemingia macrophylla*, and *Indigofera dosua* might be good hedgerow species. Although *Amorpha fruticosa* survived to 2003, many plants then died back after pruning. Like *Crotalaria cytisoides*, it might not be suitable as a hedgerow species.

Growth of girth at base

The diameter of the trunk at 10 cm above the ground for each species from 1993 to 2003 is shown in Table 8 and Figure 3. *Alnus nepalensis* grew faster than all other species and the difference increased with time; it was followed by *Albizia lebbeck*. Both of these are tree species. The other four species that survived to 2003 (*Indigofera dosua, Flemingia macrophylla, Desmodium floribundum, Amorpha fruticosa*) showed similar patterns of growth with only a slow increase in diameter after the first six years; they are all shrub species. The different growth patterns reflect the basically different nature of the habit of these species: tree species increase their diameter for many years but shrubs for only a few years.

Natural branching character

The amount of branching is an important indicator for a good hedgerow species, but there are few reports of studies of branching characteristics. The number of branches on the unpruned trees of the selected species were measured each year from 1994 onwards. The results are shown in Table 9 and Figure 4. *Amorpha fruticosa* had fewer branches than other species every year; *Albizia lebbeck* had markedly more branches than any of the other species from 1997 onwards. The other four of the species that survived, *Alnus nepalensis, Desmodium floribundum, Flemingia macrophylla* and *Indigofera dosua*, had similar numbers of branches although with slightly different patterns of increase.

The branching characteristics are indicative of suitability as hedgerow plants, but in practice many more branches would usually be expected to develop in response to pruning, and the pruning response itself might differ among species.

Fresh biomass production

Annual biomass production is an important criterion for species selection because the hedge trimmings provide the basic materials for soil improvement and can be used as fodder; biomass production will affect soil fertility improvement and/or fodder supply.

The fresh biomass production was measured on the plants in the hedgerow trials planted at all sites except site 3. Measurements were made for all the species planted as listed in Table 4; results are shown only for the five species that survived to the end of the trial. Hedgerows were pruned one to three times a year according to growth, and the total annual fresh biomass recorded up to 2004. The results are shown in Table 10. These results show the total biomass production of these species planted in the form of hedgerows under field conditions. They reflect mortality and the impact of replanting, as well as the actual potential biomass production of a particular species.

Table 10: Biomass production (kg fresh biomass/100m) at different sites

	1994	1995	1996	1997	1998	1999	2000	2001	2002			Average
Alnus nepalensis*												
Site 1		35.6	176.6	252.5	63.7	137.0	388.0	473.0	476.5	-	-	250.4
Site 2		35.3	196.2	197.2	30.3	51.8	313.0	245.3	260	-	-	166.1
Site 4	180.2	225.8	185.9	230.5	86.2	139.9	61.1	82.3	89.2	-	-	137.6
Site 5			44.8	199.5	22.2	115.9	143.1	151.5	83.3	-	-	108.6
Site 6	83.6	88.0	175.8	32.2	24.0	138.2	114.3	148.4	150.7	-	-	109.0
Site 7	48.4	125.4	161.2	81.4	7.8	41.7	64.1	86.5	*	-	-	81.2
Site 8		37.4	45.2	63.9	5.3	0.9	*	-	-	-	-	30.5
Average	104.1	83.6	127.7	151.0	34.2	89.3	180.6	197.8	211.9	-	-	126.2
Albizia lebbeck												
Site 1		26.1	31.3	59.9	28.0	27.8	91.5	103.0	115.1	172.5	25.7	1
Site 2		5.6	20.9	22.0	6.0	9.1	83.3	105.0	118.5	129.0	9.9	50.9
Site 4	52.0	57.0	46.2	36.2	13.1	21.2	19.6	25.9	29.9	11.8	6.6	29.0
Site 6	58.9	122.6	93.4	5.3	4.1	18.1	14.2	17.5	17.9	14.4	12.0	34.4
Average	55.5	52.8	48.0	30.9	12.8	19.1	52.2	62.9	70.4	81.9	13.6	45.5
Indigofera dosua												
Site 1		30.0	74.8	12.7	12.2	26.0	44.7	63.1	70.3	81.4	43.4	45.9
Site 2		46.2	81.8	8.0	10.3	11.2	40.8	69.2	72.9	90.3	13.7	44.4
Site 4		140.3	128.1	68.3	58.6	105.0	37.4	55.5	60.6	94.0	12.0	76.0
Site 5			34.8	42.8	21.7	40.1	28.6	57.2	7.8	21.1	22.1	30.7
Site 6	4.6	41.9	77.3	15.4	5.3	22.5	12.4	21.6	21.8	5.9	9.4	21.6
Site 7	16.4	56.2	29.2	16.6	4.3	0.5	1.4	7.8	9.3	11.8	13.9	15.2
Site 8		2.6	3.9	46.4	23.5	26.1	41.1	61.1	66.0	33.3	44.1	34.8
Site 9			111.6	13.6	6.4	0.7	3.1	6.3	16.3	36.3	34.2	25.4
Average	10.5	46.6	54.4	29.8	17.8	29.0	26.1	42.7	40.6	46.8	24.1	36.8
Flemingia macrophylla												
Site 1		13.0	48.6	57.5	56.5	80.2	115.9	166.8	172.4	186.4	309.3	120.7
Site 2		7.6	37.1	35.6	49.1	65.4	112.6	201.5	210.6	227.1	123.4	107
Site 4			88.0	34.0	58.6	126.6	66.3	101.7	105.3	108.3	98.7	87.5
Site 6			67.5	30.6	14.9	100.5	27.2	32.5	49.6	109.1	84.1	57.3
Site 7	8.9	27.4	56.9	47.2	18.1	0.3	22.1	30.7	31.7	19.9	11.9	25.0
Site 8		30.6	34.9	19.1	17.8	2.5	13.7	30.7	15.8	25.6	30.2	22.1
Site 9			6.7	12.2	5.5	12.5	8.8	12.9	13.8	39.9	16.1	14.3
Average	8.9	19.7	43.2	33.7	28.8	55.4	52.4	82.4	85.6	102.3	96.2	55.3
Desmodium floribundum												
Site 4			2.7	12.5	3.4	7.2	3.3	8.6	14.5	11.9	3.6	7.5
Site 9			68.4	2.2	5.6	1.6	5.0	18.4	19.6	30.6	27.2	19.8
Average			35.6	7.4	4.5	4.4	4.2	13.5	17.1	21.3	15.4	13.7

* Shoot borer beetle infestation, died back; all *Alnus* plants replaced with *Flemingia macrophylla* at sites 1,2,4,7, and 8 in 2003 and sites 5 and 6 in 2004 because of beetle infestation.

In terms of the overall average over the nine years at the different sites, *Alnus nepalensis* had the highest fresh biomass production (126 kg/100m) and *Desmodium floribundum* the lowest (14 kg/100m). *Indigofera dosua*, *Albizia lebbeck,* and *Flemingia macrophylla* had a similar production of around 40-55 kg/100m. Field observation also indicated that *Desmodium floribundum* grew slowly, even though it is a local species at the site.

The figures can be converted to give approximate values of production per hectare. Using an estimated total hedgerow length of 2,000 to 2,500m and inter-hedgerow distance of 4 to 5m, the fresh biomass production of *Alnus nepalensis*, *Flemingia macrophylla*, *Indigofera dosua*, *Albizia lebbeck,* and *Desmodium floribundum* is calculated to be approximately 4.9-6.2, 1.8-2.7, 1.5-1.9, 1.6-2.0, and 0.6-0.7 t/ha, respectively. This is much lower than the fresh biomass production reported for plants used as hedgerows in the tropics, or for *Leucaena leucocephala* and *Tephrosia candida* used for hedgerows in subtropical Ningnan in China (Sun Hui et al. 2001). The biomass production declined considerably in 1998 for all species, reflecting the high plant mortality in that year following frosts.

Different biomass production trends were observed at different sites for the same species. For example, the biomass production of *Albizia lebbeck* increased with age at Sites 1 and 2, but declined with age at Sites 4 and 6. Similar variations were observed for the other species.

Discussion

Important criteria for species selection for hedgerows

The prerequisite for the successful establishment of sloping agricultural land technology is the selection of a suitable hedgerow species for the conditions and requirements at a particular site (Kang 1993). We have frequently been asked to name suitable species. However, selection of appropriate species for hedgerows is not a precise science; it requires extended trials and demonstration, as shown again in the trials at the Godavari site. Many factors influence species performance; specific soil and microclimate conditions can mean that a species that performs well at one site, performs poorly at a site which is physically not far distant. Equally, species that appear to be promising may not survive the extremes of weather that can be experienced over a number of years, whereas other less promising species may prove more hardy in the long term. At Godavari, some species, like *Tephrosia candida*, performed quite well initially, but later proved to be unsuitable, whereas some species, like *Leucaena leucocephala,* performed less well initially, but proved to be good hedgerow species later. There are other farmer related factors that need to be taken into account, for example the use to which the hedgerow alleys will be put, the need for soil improvement, the need for fodder or fuel, and availability of labour for hedgerow management.

When selecting a hedgerow species, it is important to have a good knowledge of the site conditions. Factors that affect species selection include climate, particularly temperature (both average and extremes) and rainfall/drought, and soil type. For example, species that grow well on alkaline soils usually grow poorly on acidic soils, and vice versa; unusual extreme temperatures can kill whole groups of plants that are otherwise well adapted, as experienced at Godavari in 1998. Soil samples should be analysed and a survey made of the existing vegetation. Climate data are needed.

Socioeconomic data are also important. For example, what are the local sources of fuelwood? What role do livestock play in the local and household economy? Should the species selected be more suitable for soil improvement, fuelwood, or fodder production? Maximising the benefits of the hedgerow system means choosing species that have multiple uses. In the past, most work has focused on woody legumes because these are nitrogen fixers and many also produce good fodder.

Our experience suggests that in order to have sufficient information to select a suitable species for planting as hedgerows, a site characterisation should be made that includes the following information (modified from MacDicken 1994).

- Geographical location (tropical, subtropical, temperate)
- Elevation
- Slope and aspect
- Mean annual rainfall
- Seasonal rainfall distribution pattern
- Maximum length of dry season
- Mean annual temperature
- Mean minimum temperature of coldest month
- Mean maximum temperature of hottest month
- Absolute minimum temperature over a representative time period
- Soil nutrient analysis
- Surface soil texture: sand, loam, clay
- Soil depth to impermeable level
- Soil drainage
- Soil pH
- Survey of existing vegetation

Our own work over the past decade and information from other regions suggest that the best species for hedgerows should be selected using the following criteria.

- Woody, perennial, and fast growing
- Adaptable to local climate
- Good coppicing capacity
- Good biomass production
- Able to grow when planted very thickly
- Preferably nitrogen fixing
- Adaptable to local soils
- Deeply rooted
- Easy to propagate

The first five of these criteria are critical, they must all be fulfilled or the species will be rejected as it cannot form a successful hedgerow. Additional criteria include compatibility with intended primary crops, and good production of material for additional requirements like fuelwood or fodder (Shannon, Isaac and Brockman 1997).

In practice there will be very few if any species that meet all the above criteria for a specific region, especially in regions with low temperatures. Priority should be given to different aspects according to the region. It is important to identify the prime objective of applying hedgerow technology and to choose the key criteria for species selection accordingly. For example, in regions where soil conservation is the most important task, the key criteria for selecting hedgerow species should be 'deeply rooted', 'easily propagated', and 'able to grow vigorously at very high density'.

Recommended species

Table 11 summarises the characteristics of the species evaluated in the hedgerow and growth trials in terms of the criteria listed above. All species were woody and perennial. Frost resistance (adaptability to local climate), coppicing (resistance to), and biomass (good biomass production) were the most important criteria for the species evaluation.

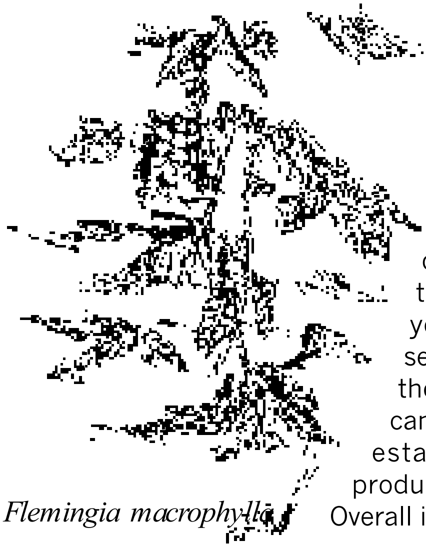
Table 11: Characteristics of species in the advanced trials

Species	Frost resistance	Coppicing	Biomass	Growth rate	N_2 fixation	Rooting	Propa-gation	Other uses
Acacia mearnsii	3	3	2	1	1	2	2	3
Albizia lebbeck	1	2	2	2	2	2	2	3
Albizia procera	3	3	3	2	2	3	2	3
Alnus nepalensis	1	3	1	1	1	2	3	2
Amorpha fruticosa	2	3	3	2	2	2	1	2
Crotalaria cytisoides	1	3	2	2	2	2	2	3
Dalbergia sissoo	3	1	3	3	2	2	3	3
Desmodium floribundum	1	2	3	3	2	2	2	3
Desmodium rensonii	3	1	2	2	1	2	3	2
Flemingia macrophylla	1	1	2	2	1	1	2	2
Indigofera dosua	1	2	2	2	2	1	1	2
Leucaena leucocephala	1	1	1	1	1	1	1	1
Robinia pseudoacacia	2	2	2	3	2	2	2	2
Tephrosia candida	3	3	2	2	2	2	3	2

Ranking: 1: good; 2: moderate; 3: poor or difficult; shaded rows are recommended species

Based on the above criteria and the overall performance at the Godavari Site, the following species are recommended (in the order shown) as potentially suitable hedgerow species in mid hill areas of Nepal and other areas with similar biophysical conditions.

- *Flemingia macrophylla*
- *Leucaena leucocephala*
- *Indigofera dosua*
- *Alnus nepalensis*
- *Albizia lebbeck*

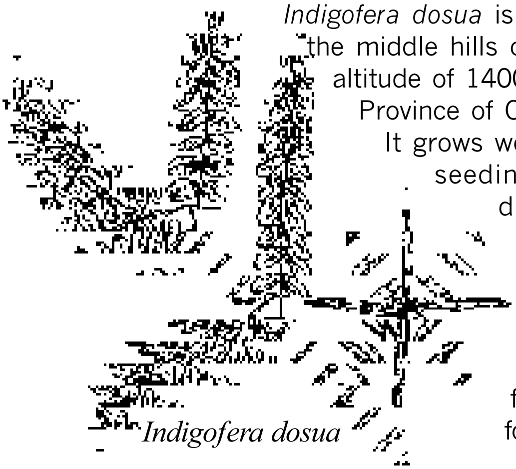


Flemingia macrophylla

Flemingia macrophylla is an indigenous species, although the seed used in the trial was obtained from the Philippines. It has been shown to be a satisfactory hedgerow species in Mindanao in the Philippines and grows satisfactorily up to an altitude of at least 1800m masl in Nepal; information is lacking from higher elevations. It did not perform as well as *Alnus nepalensis* during the first few years, but when assessed over eight years its performance was very promising. The seeds only need hot water treatment before seeding, the germination rate is satisfactory, and the seed can mature normally at the site. Hedgerows can be established easily with direct seeding. Biomass production is moderate but the roots are very deep. Overall it is one of the most suitable species for hedgerows.

Leucaena sp.

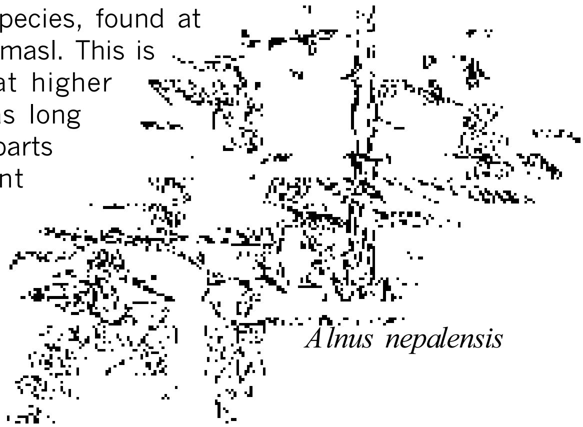
Leucaena leucocephala is probably the most widely used and extensively studied species among those used in hedgerow intercropping systems. It is a domesticated species, although some of the seed used was obtained from Sichuan in China, and the Philippines. The plants grown from Philipino and Nepali seed performed quite poorly during the first 3-4 years of the trials, and all the plants for monitoring growth died two years after transplanting. However, plants grown later from Chinese seed and planted in hedgerows performed satisfactorily. The species can be established easily by direct seeding and starts bearing seeds after 3-4 years. It is easy to obtain large amounts of seed. The species has a very deep root system, the biomass production is satisfactory, and the young leaves provide good fodder for cattle, goats, pigs, and fish.



Indigofera dosua

Indigofera dosua is an indigenous species. It grows widely in the middle hills of Nepal. It was introduced to a site at an altitude of 1400-1500m masl in Ningnan County, Sichuan Province of China where it has performed satisfactorily. It grows well and can be established easily by direct seeding or transplanting. It grows vigorously during the monsoon and has a deep root system, but total biomass production is not very good, probably as a result of its shrub habit. The fresh leaves are not eaten by livestock, but it would be useful to test whether wilted leaves can be used as fodder, as has been reported for example for *Calliandra calothyrsus.*

Alnus nepalensis is an indigenous species, found at elevations between 1,000 and 2,500 masl. This is one species that can be planted at higher elevation. It grows very well and has long been used by local people in many parts of the HKH region for different purposes. It can be managed to improve soils and to provide fuelwood. However, one important constraint is that it is extremely difficult to establish by direct seeding. The seeds are very small and lose their ability to germinate within six months. The hedgerows at the Godavari site were established by transplanting, but this involves considerable additional expense in terms of raising, transporting, and planting of seedlings. A further drawback is that the young leaves of this species can't be used as fodder. In addition, the plants at the Godavari site were highly susceptible to insect herbivores. Thus although *Alnus nepalensis* was the species used to establish the greatest number of hedgerows at the Godavari Site, it is now less strongly recommended than other hedgerow species.



Alnus nepalensis

Albizia lebbeck is also an indigenous plant. It can be established by direct seeding. Its biomass production is good and the leaves can be used as fodder. One constraint is that it does not root as deeply as *Flemingia macrophylla* and *Leucaena leucocephala*.

Albizia lebbeck

Unsuccessful species and species meriting further testing

Of the 30 species tested, only five were finally identified as having high potential for widespread use as hedgerow species. Clearly selection and screening of hedgerow species is quite difficult.

Some species that showed early promising growth later proved unsuitable. These included *Tephrosia candida*, *Cajanus cajan*, and *Crotalaria cytisoides*. The first two have only a short life expectancy: *Tephrosia candida* usually dies back within 4-5 years and *Cajanus cajan* after 1-2 years. *Crotalaria cytisoides* is sensitive to pruning. All three species would need to be replanted frequently. *Dalbergia sissoo* is basically a timber species and has never been used to establish hedgerows. Little is known about its resistance to coppicing or compatibility with intended primary crops. It is usually found in hot places and low temperature may have been the main cause of its failure.

Some local species, such as *Desmodium floribundum*, were well suited to the local conditions but cannot be recommended as hedgerow species because of their slow growth rate and small biomass production.

Species like *Cassia siamea*, *Calliandra calothyrsus,* and *Desmodium rensonii* were simply unsuited to the conditions and completely unsuccessful. They should not be used to establish hedgerows.

In some cases like *Robinia pseudoacacia, Leucaena diversifolia,* and *Milletia japonica*, the reasons for failure were unclear and some species, especially those not of tropical origin, may merit further testing. Because little was known about these species' use as hedgerow species, they may not have been properly managed, leading to poor initial performance. They were not included in the advanced trials as there was insufficient planting material available.

There may well be other species not yet tested that could have potential as hedgerow species. Possibilities include *Elaeagnus parvifolia, Elaeagnus latifolia, Dalbergia latifolia,* and *Lespedeza* spp.

There are still some open questions about causes of success and failure. For example, *Tephrosia candida* was tested because it had proven very successful and lasted for over 10 years at Ningnan, in Sichuan, China. Hedgerows of *Tephrosia candida* were easily established by direct seeding in trials in the Chittagong Hill Tracts of Bangladesh, northeast India, and in south Nepal near Mugling, but most of them died after 3-5 years, particularly in Godavari and the Chittagong Hill Tracts. Considering the different climates at these sites, low temperature seems unlikely to be the key factor in plant death. It has been suggested that pruning time and height might have been a factor, the bushes were pruned after one year in Ningnan, after only 4-5 months at Godavari, and not at all in the Chittagong Hill Tracts. Further studies are needed to find out the cause, and identify those areas where *Tephrosia candida* is likely to be useful as a hedgerow species. *Tephrosia candida* might also be useful for other applications in the region, for example it can be used to suppress weeds if they pose a problem because it can be established very easily and grows vigorously.

Indigenous vs exotic species

The key element in sloping agricultural land technology is the use of nitrogen-fixing trees or shrubs. However, while there are a great number of such species, there are only around ten that have been used widely in hedgerow intercropping systems in different parts of the world. Extensive trials have been conducted to select appropriate hedgerow species — but a review of the literature suggests that they have all concentrated on a few species, with two-thirds of the studies being on *Leucaena leucocephala* alone. The information available is also mostly limited to these species. The most common species used in hedgerow technology are *Leucaena leucocephala, Calliandra calothyrsus*, and *Gliricida sepium*, and in addition in Asia *Flemingia macrophylla* and *Desmodium rensonii*. Some other species have been said to show potential as hedgerows, for example *Indigofera anil,* but are largely used locally.

Reports of successful applications of SALT (or CHIAT) indicate that the easiest way to establish the technology is to use species that have been used successfully elsewhere in regions with a similar environment and climate. However, these species are likely to be exotic species in the new region, and care should be taken. There are increasing reports of ecological problems caused by exotic species which can turn out to be aggressively invasive (weeds) when introduced to a new environment. Two classical cases are those of *Eupatorium adenophorum* (eupatorium) and *Eichhornia crassipes*. While the first species was introduced to the HKH region last century, possibly unintentionally, from tropical America, the second was introduced intentionally from South America as forage for livestock (pigs). Eupatorium is causing major ecological and economic problems in both China and Nepal – where it is known as banmara or forest killer – as a result of its invasive behaviour and aggressive competition with indigenous forage and other species. Its aggressive growth usually prevents growth of other useful plants and it has caused serious problems in many lakes, reservoirs, and rivers in China. Special care needs to be taken when introducing exotic plants.

Before establishing hedgerows, as many potential local species as possible should be tested in order to screen for appropriate hedgerow species. Suitable indigenous species should be given priority to avoid potential problems when introducing exotics. Indigenous species have other potential advantages: they are already adapted to the environment; planting materials may be readily available; and growth of natural stands can provide some indication of possible performance under cultivation. There has been a rapid increase in interest in hedgerow technology and applying it in subtropical and temperate regions, and there is now a great need to test more potential hedgerow species, especially species suitable for cooler areas.

Four of the five species that proved to be successful hedgerow species in the nine years of trials at Godavari were indigenous species (although the seed for one was obtained from elsewhere): *Alnus nepalensis*, *Flemingia macrophylla*, *Indigofera dosua*, and *Albizia lebbeck*. Two of these, *Alnus nepalensis* and *Indigofera dosua,* were used to establish hedgerows for the first time. *Leucaena leucocephala* was the only introduced species that proved to be a good hedgerow species in the long-term, although its performance in the first few years was also not satisfactory.

Lessons and Implications for Further Work

Sloping agricultural land technology (SALT), contour hedgerow intercropping technology (CHIT, CHIAT), or alley cropping (the three most common names for the practice) has been promoted for nearly 30 years as a useful technology to support use of, and prevent or reverse degradation of, sloping agricultural land. Despite its considerable benefits, spontaneous adoption by farmers has proven quite limited. Various reasons have been identified for this, the main ones being the lack of direct and visible cash income and the drop in productivity in the first years of establishment (Tang Ya 1999b). Most hill farmers have very small land-holdings and the effective land area available for sowing crops decreases when hedgerows are planted leading to a drop in production; this is more than offset by the increase in yield resulting from the improvement in soil fertility – but only after three years or so. Understandably, farmers with a family to feed find it difficult to wait so long. Another important factor is the ease of hedgerow establishment. In the present study, hedgerows were established by transplanting, which not only requires a lot of labour but also involves high inputs. This might explain in part the low adoption of the technology in neighbouring villages. Availability of planting material is also very important. Direct seeding is the best and most economic method for hedgerow establishment, the advantages include low cost, ease of doing, low labour requirement, and ease of ensuring the required planting density. It is important that testing, selecting, and demonstrating of any technology takes economic factors into consideration. We hope also that by demonstrating the technology at Godavari, farmers will be able to see for themselves the overall gain in productivity and land quality, and will be in a better position to make a decision as to where the method will be economically viable and whether it might even be the only sustainable way of using some marginal slopes.

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Typical view in the spring of terraces formed by planting hedgerows of nitrogen-fixing species along contour lines. The upper terraces are planted with fruit trees intercropped with radish and mustard. The crops on the lower terraces have been harvested. Regenerating forest can be seen in the background.

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