Nature's Bounty
Nitrogen-Fixing Plants for Mountain Farmers

Tang Ya

Godavari ICIMOD

Focus on Godavari #2

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**' features 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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Focus on Godavari #2

International Centre for Integrated Mounain Development
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Editorial Team
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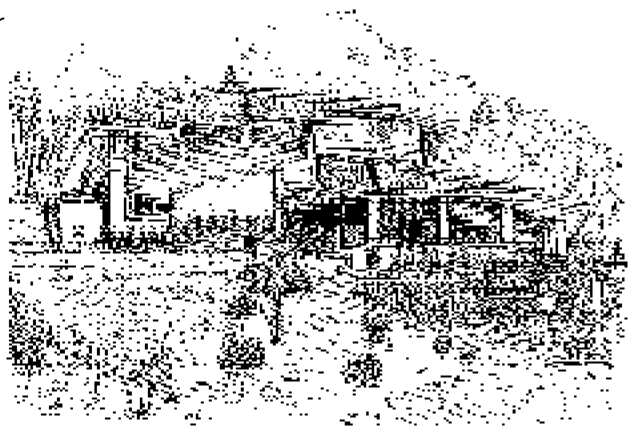
Foreword
Focus on Godavari

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

Executive Summary

Environmental degradation is generally considered to be one of the main obstacles to sustainable development in the Hindu Kush-Himalayan (HKH) region. Agriculture in the HKH is showing a trend towards unsustainability, which has been one of the root causes of poverty in the region. More than three-quarters of the region's inhabitants depend on agriculture for their livelihood, and poverty reduction will only be achieved with sustainable agricultural development.

Nitrogen deficiency is one of the major factors involved in declining soil fertility and land productivity. In many places, chemical nitrogen fertiliser has been used to replenish the soil nitrogen reserve; but continued unselected, and often excessive, application of chemical nitrogen fertiliser has resulted in environmental problems. Equally, in many parts of the HKH region chemical nitrogen is either too expensive or not available. Biological nitrogen fixation offers a simple and cheap method of replenishing soil nitrogen; and nitrogen-fixing plants offer a range of other benefits and opportunities for crop productivity, soil improvement, land reclamation, forest conservation and many others. Promoting the use of nitrogen-fixing plants can contribute considerably to sustainable mountain development. However, in order to be able to exploit the potential of biological nitrogen fixation to the full, it is important first to understand the principles of application, the different types of plants involved, and the different possible uses of these different species in agriculture and forestry.

This book provides a brief description of the principles of biological nitrogen fixation, the different types of nitrogen-fixing plants – leguminous and non-leguminous – and the major potential uses of these plants to support agricultural development in the HKH region. Separate sections are devoted to various means of improving soil fertility, soil conservation, rehabilitation of degraded land, development of woody fodder, development of fuelwood crops, and the use of terrace risers.

The unique characteristics of nitrogen-fixing plants – including their ability to fix nitrogen from the air, to colonise very poor soils, and to act as pioneering plants, fast growth, and their high content of protein, calcium and other nutrients – can be used to help achieve sustainable mountain development by meeting people's basic needs for fertilisers, fodder, and fuelwood, as well as providing an important source of improved nutrition.

Preface

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Acronyms and Abbreviations

ACIAR	Australian Centre for International Agricultural Research
BNF	biological nitrogen fixation
CHIAT	contour hedgerow intercropping agroforestry technology
HKH	Hindu Kush-Himalaya(s/n)
ICIMOD	International Centre for Integrated Mountain Development
NFP	nitrogen-fixing plants
SALT	sloping agricultural land technology

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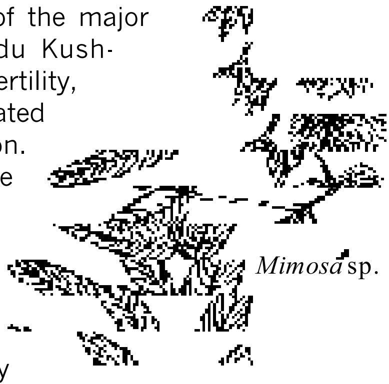
Photo N_2 Plants board, Godavari

before chapter 1

Chapter 1

Nitrogen-Fixing Plants

INTRODUCTION



Mimosa sp.

Environmental degradation is considered to be one of the major obstacles to sustainable development in the Hindu Kush-Himalayan (HKH) region. Soil erosion, declining soil fertility, declining land productivity, deforestation – and associated out migration – are problems seen across the region. Agriculture provides the major, and often only, source of livelihood of around 80% of the HKH population, but is becoming increasingly unsustainable as a result of increasing population pressure and degradation of the existing agricultural resources. Unsustainable agricultural development is one of the root causes of poverty in the region; and achieving the goal of poverty reduction will depend to a large extent on achieving sustainable improvement in agricultural practices. Tackling the problems of declining soil fertility, soil erosion, and lack of cash income is becoming ever more urgent.

Nitrogen is a key component of protein and other important plant compounds, but it is often the most deficient nutrient in the soil, limiting plant growth and contributing to reduced agricultural yields throughout the world. The deficiency in soil nitrogen results from continual loss by such processes as microbial denitrification, soil erosion, leaching, chemical volatilisation, and – perhaps most important – through the removal of crops and residues from cropland. The nitrogen in agricultural soils needs to be replenished periodically to maintain an adequate level for crop production. Although the earth's atmosphere contains about 78% nitrogen, plants are usually unable to use this nitrogen directly. Nitrogen-fixing plants are the exception; these plants have an unusual advantage in being able to obtain gaseous nitrogen through the action of symbiotic nitrogen-fixing microorganisms that most commonly live within a specialised nodule on the roots of the plants. These microorganisms can take nitrogen in the form of N_2 from the air and convert it into the form that plants can use.

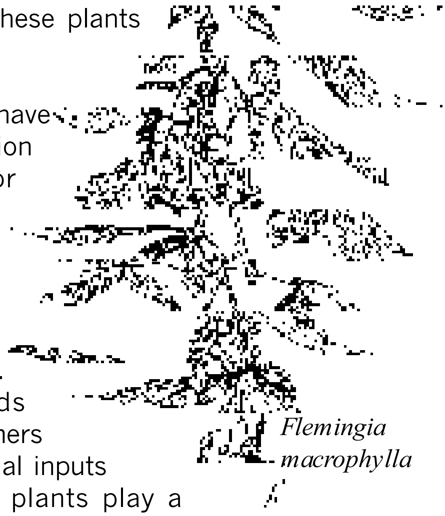
In former times, nitrogen levels were maintained in agricultural soils by addition of manure, use of careful crop rotation and co-cultivation systems including nitrogen-fixing plants, and ploughing in of crop residues, but in modern farming systems it is more commonly accomplished by adding chemically fixed nitrogen in the form of commercial inorganic fertilisers. Worldwide, the consumption of fertiliser nitrogen increased from 3.5 million metric tonnes in 1950 to 80 million metric tonnes in 1989 (TFI 1990), and 82 million metric tonnes in 2001/02 (TFI 2004). China and India, two of the ICIMOD member countries, rank first and third worldwide, respectively, in annual consumption of chemical fertiliser nitrogen (FADINAP 2004).

Although easy to apply, chemically fixed nitrogen fertiliser has many disadvantages compared to natural fertiliser. Chemical fertiliser nitrogen is used inefficiently by crops; in the HKH the efficiency of use varies from as low as around 30% in China (Peng 1999) to about 50% on average. In contrast to this, biologically fixed nitrogen can be used completely by crops. This means that about two metric tonnes of industrially fixed nitrogen at least are needed as fertiliser for crop production to equal the effects of one metric tonne of biologically fixed nitrogen. The vast amounts of chemically fixed nitrogen fertiliser used in the world are leading to an imbalance in the global nitrogen cycle, pollution of groundwater (sometimes to an alarming degree) and an increase in the cost of production inputs, among others.

The total annual terrestrial input of nitrogen from biological nitrogen fixation (BNF) is estimated to be somewhere between 139 and 170 million tonnes (Burns and Hardy 1975; Paul 1988 [cited in Peoples, Herridge, and Ladha 1995]; Pimentel et al. 1997; Ishizuka 1992). BNF is a significant factor in natural N cycles and is estimated to provide some 65% of the nitrogen currently used in agriculture. BNF nitrogen has considerable advantages in comparison with chemically fixed nitrogen, in particular that all of the biologically fixed nitrogen can be assimilated so that there is no groundwater pollution, and that it is cost free – and freely available as long as the appropriate plants can be grown. BNF nitrogen is expected to become increasing important in future crop productivity, particularly for sustainable systems (Thomas et al. 1997); the significance of BNF as a major mechanism for managing nitrogen recycling in agricultural and forest systems cannot be overemphasised.

In the HKH region, especially, where commercial chemical fertilisers are either unavailable or too expensive for local people to buy, and soil degradation is a major limiting factor in crop production, BNF can play a major role in agricultural development. However, in order to be able to exploit its potential to the full, it is important first to improve our understanding of BNF and its application to agricultural and forestry production. In this book we briefly describe the principles of biological nitrogen fixation, the different types and methods of action of nitrogen-fixing plants, and the major uses of these plants in mountain regions.

Most of the technologies described in this book have been demonstrated at the Test and Demonstration Site maintained by the International Centre for Integrated Mountain Development (ICIMOD) at Godavari, near Kathmandu in the mid hills area of Nepal. This site is dedicated to developing, testing, and demonstrating appropriate technologies for sustainable agricultural development in the Hindu Kush-Himalayan region. No chemical fertilisers are used; the methods investigated are intended for use by the small farmers of the region who have little recourse to commercial inputs or capital intensive techniques. Nitrogen-fixing plants play a major role in ensuring the viability of such systems.



Flemingia macrophylla

Biological Nitrogen Fixation

Biological nitrogen fixation (BNF) is a process in which atmospheric nitrogen is converted to ammonia by the enzyme nitrogenase. Essentially, there are two processes: symbiotic and non-symbiotic. In symbiotic processes, nitrogen-fixing microorganisms are associated with plants either within nodules attached to the plant roots, or in free association with the roots and/or leaves of the plants. In non-symbiotic processes the organisms involved are free-living. Some of the typical organisms involved are listed in Table 1. This publication is mainly concerned with nitrogen fixation by symbiotic processes, in particular by plants that have root nodules.

Table 1: Selected biological nitrogen-fixing organisms (modified from Ishizuka 1992 and Pokhriyal & Mathani 1989)
Symbiotic nitrogen-fixing systems Legumes with *Rhizobium* and *Brachyzhirobium* Non-legumes with *Frankia* Lichens with *Nostoc* Waterfern *Azolla* with *Anabaena* Non-nodulated plants with root and leaf associated microorganisms like *Tripsacum* and *Azospirillum*
Non-symbiotic or free-living nitrogen fixers Obligate aerobes, e.g., *Azotobacter vindelandii* Facultative anaerobic bacteria, e.g., *Klebsiella pneumoniae* Obligate anaerobes, e.g., *Clostridium pasteurianum* Phototrophic bacteria, e.g., *Rhodospirillum rubrum* Blue-green algae, e.g., *Nostoc muscorum* and *Anabaena cylindrical*

Nitrogen-Fixing Plants

Nitrogen-fixing plants are plants that support biological nitrogen fixation through a symbiotic association between the plants and nitrogen-fixing microorganisms. The great majority of these plants belong to the legume family, but there are also a number of non-leguminous species that can fix nitrogen from the atmosphere.

Legumes and Non-legumes

Legumes are the best known nitrogen-fixing plants, but a few non-leguminous species can also form a symbiotic relationship with microorganisms to fix atmospheric nitrogen. Legumes most commonly form nodules with *Rhizobium* bacteria, while non-leguminous plants form nodules with actinomycetes *Frankia*.

Leguminous species

Legumes are a large family of flowering plants – trees, shrubs, vines, and herbs – that produce podlike fruit (legumes) that split spontaneously along two seams to release the seeds they contain, which are attached along one of the seams. The legume family (or Fabaceae) contains about 650-750 genera with 13,000-18,000 species in three subfamilies: Caesalpinioideae, Mimosoideae, and Papilionoideae. The best known edible legumes are peas and beans (Papilionoideae), but legumes also include such plants as clover, lupins, wisteria, and some brooms (all Papilionoideae), acacia (Mimosoideae), and bauhinia and senna (Caesalpinioideae), among many others. There are both herbaceous and woody legumes; the Caesalpinioideae and Mimosoideae subfamilies are characterised by more woody plants and the Papilionoideae by more herbaceous plants.

Mutualistic symbiosis is a mutually beneficial relationship between two organisms. Symbiotic nitrogen fixation occurs in plants that harbour nitrogen-fixing bacteria within their tissues. Both the host plant and the bacteria can survive independently, but living together is beneficial to both. The host plant provides the bacteria with energy-rich carbohydrates and some other compounds, while the nitrogen-fixing bacteria supply the host plant with nitrogen in the form of ammonia. Nitrogen fixation can only take place when the bacteria are associated with the plant. The best-studied example is the association between legumes and bacteria of the genus Rhizobium.

Most leguminous species can form a mutualistic symbiotic association with nitrogen-fixing bacteria, although the proportion in the subfamilies varies. In most cases the bacteria are contained in specialised root nodules, Of some 3,000 leguminous species examined, more than 90% were found to have root nodules – 98% of the Papilionoideae, 90% of the Mimosoideae, and about 30% of the Caesalpinioideae (Allen and Allen 1981). Of the 72 nitrogen-fixing species of Caesalpinioideae found in Allen and Allen's study, 44 were from the genus cassia (Cassia); it seems that most of the other members of the Caesalpinioideae are not nitrogen-fixing. Some of the more common leguminous plant genera in the HKH region are listed in Table 2.

Table 2: Some common leguminous plant genera in the HKH region		
Sub-family	Genus	Common name
Caesalpinioideae	*Caesalpinia*	caesalpinia
	Delonix	flamboyant tree
	Gleditsia	honey locust
	Cassia	sena
	Tamarindus	tamarind
	Bauhinia	bauhinia
Mimosoideae	*Albizia*	albizia
	Acacia	acacia
	Leucaena	ipil-ipil
	Mimosa	sensitive plant/mimosa
	Prosopis	mesquite
Papalionoideae	*Sophora*	pogoda tree
	Meliotus	sweet clover
	Medicago	medic
	Trifolium	clover
	Glycine	soya bean
	Cajanus	pigeon pea
	Flemingia	flemingia
	Erythrina	coral bean
	Lespedeza	bush clover
	Campylotropis	clover shrub
	Desmodium	tick clover
	Indigofera	indigo
	Tephrosia	tephrosia
	Milletia	milletia
	Robinia	locust
	Sesbania	sesbania

Non-leguminous species

In addition to the leguminous species, there are some 200 species of non-leguminous nitrogen-fixing plants, almost all of them woody. Most are angiosperms – about 170 species of 17 genera in 8 families; typical species include alder, beefwood, and bayberry. There are also a few nitrogen-fixing gymnospermous species, especially members of the Cycadaceae, such as cycads (*Cycas, Encephalartos, Macrozamia*), and some other plants like podocarpus (*Podocarpus*). The most common non-leguminous nitrogen-fixing plants in the HKH region are listed in Table 3. Although less well-known than the legumes, they include some important cash plants like seabuckthorn (*Hippophae rhaminoides*) and elaeagnus (*Elaeagnus* spp.) which can play an important role in improving mountain livelihoods.

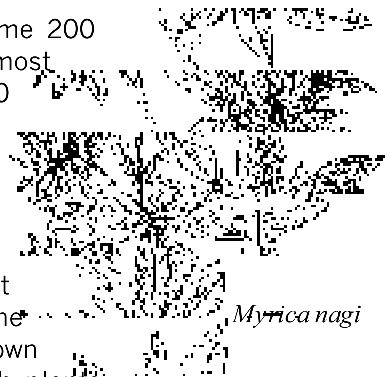

Myrica nagi

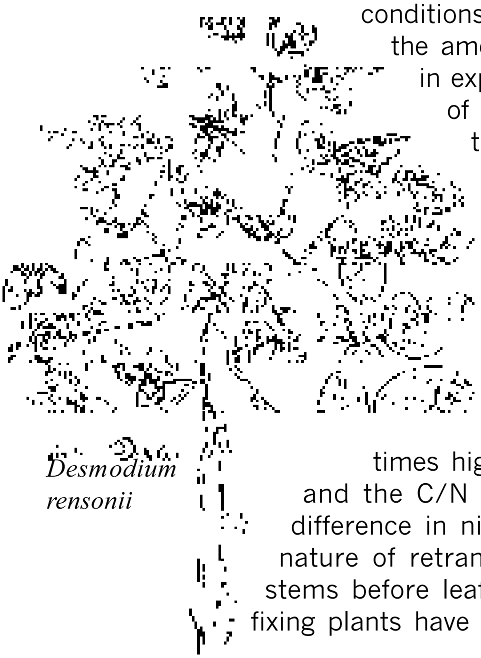
Table 3: Some common non-leguminous nitrogen-fixing plant genera in the HKH region

Family	Genus	Common name
Betulaceae	*Alnus*	alder
Elaeagnaceae	*Elaeagnus*	wild olive
	Hippophae	seabuckthorn
Casuarinaceae	*Casuarina*	beefwood
Coriariaceae	*Coriaria*	coriaria
Rosaceae	*Dryas*	dryad
Myricaceae	*Myrica*	bayberry, sweet gale
Ulmaceae	*Trema*	trema

Methods of action

The nitrogen fixed by the nodule bacteria on the roots of nitrogen-fixing plants may enter the crops or soil in three ways. First, it may be used by the host plants themselves. Second, the nitrogen can pass directly into the soil, either by excretion or more often by the sloughing off of the plant roots and especially their nodules. Third, the nitrogen from legume residues enters the soil as the residues decay, and becomes available to the succeeding crops.

The actual amount of nitrogen fixed by nitrogen-fixing bacteria varies considerably and is determined by a number of factors. The conditions of the soil, especially aeration, drainage, moisture, pH, and the amount of active calcium, are of prime importance. The rates of fixation of nitrogen by nitrogen-fixing plants also vary widely, and the nitrogen fixed by a particular species will be different under different conditions. Addition of chemical fertilisers can decrease the amount of nitrogen fixed by organisms, as shown in experiments with clover (Walker et al. 1956). Use of large amounts of nitrogen fertiliser may reduce the efficiency of nitrogen-fixing plants. Field studies are needed to determine the amount of chemical fertiliser that can be used without impairing the nitrogen fixation capacity of nitrogen-fixing plants.



Desmodium rensonii

The fallen leaves of nitrogen-fixing plants have a higher nitrogen content than those of other plants: the nitrogen content of leaf litter from nitrogen-fixing plants was found to be 2-3 times higher than that of other plants (He et al. 1997) and the C/N ratio 2.5 times lower (He et al. 1999). The difference in nitrogen content is mainly due to the different nature of retranslocation of leaf nitrogen into branches and stems before leaf fall: nitrogen-fixing plants and non-nitrogen-fixing plants have a different strategy for conserving nitrogen. In the HKH region Alnus nepalensis and Albizia stipulata retranslocated 2-3 times less nitrogen than non-nitrogen fixing associate species thus retaining more in the leaves (Sharma et al. 1994, 1995). This enables more release of nitrogen to the soil from fallen leaves – nitrogen which is then available to non-nitrogen-fixing plants for uptake. Most leaf litter nitrogen enters the soil, and nitrogen from nitrogen-fixing plant litter enters the soil faster as the decomposition rate is faster than that of litter from other plants.

Both leguminous and non-leguminous nitrogen-fixing plants are important nitrogen-fixing sources and are the main contributors of nitrogen inputs in terrestrial ecosystems. They play a major role in global nitrogen cycling and balancing. Nitrogen fixed by leguminous plants is thought to account for about half the total biologically fixed nitrogen on earth (Zhou Xiangquan, 1983; Zhou Xiangquan and Han Shufeng, 1989). Until now, theoretical research on leguminous plants has mainly focused on herbaceous leguminous fodder species with little investigation of woody species, whereas applied research has focused on the woody species.

Nitrogen-fixing plants not only increase soil nitrogen content, they also improve the organic matter status of soil and thus improve such properties as water retention

Alnus nepalensis

Chapter 2

Uses of Nitrogen-Fixing Plants

Improvement of Soil Fertility

One of the best known uses of nitrogen-fixing plants (NFPs) is to improve soil fertility. For centuries, farmers have known that certain crops such as clovers, alfalfa, peas, and beans can improve the soil and increase yields of cereals planted after, or together with, these plants. These crops are all nitrogen-fixing plants and they enrich the soil by improving the nitrogen status. Furthermore, if the foliage and roots are left in the ground, they can be a valuable source of organic matter, and fresh leaves used as manure can also be a valuable source of nitrogen. The fresh foliage of legumes generally contains from 2.5 to 4% (dry weight) of nitrogen.

Restoration and maintenance of soil fertility has become critical for agricultural development. In recent times, the most common response to declining soil fertility has been to use synthetic fertilisers, especially nitrogen. Agriculture has become increasingly dependent on chemical fertilisers and pesticides to produce food. However, these chemicals can have adverse effects on the rural population, the environment, and on food safety. Furthermore in marginal farming areas like those found in large parts of the HKH region, where subsistence farmers depend for their livelihood on the produce from small areas of land with often low productivity, chemical fertilisers are often not a viable option. Chemical fertilisers may not be available in the more isolated areas, and are anyway too expensive except where crops are being produced primarily for sale. In addition, a large portion of added fertiliser may be washed out under the monsoon conditions that prevail in the region.

Peas, a classic crop for soil improvement

There is a clear need for changes in agricultural production methods, with the objectives of sustainability, economic production, protection of the environment, conservation of natural resources, and reduction in the use of synthetic chemicals. With the current emphasis on the use of renewable resources for environmentally sustainable development, it is time to reasess the potential for biological nitrogen fixation to complement or gradually replace fertiliser inputs, and to be used as a major method for improving the N fertility of agricultural land. The use of nitrogen-fixing plants to improve soil fertility can considerably reduce the need for fertiliser nitrogen and is a key component in sustainable agricultural.

The main areas of application of nitrogen-fixing plants in soil fertility management are described briefly in the following sections. Most of these areas of application focus on herbaceous plants. Researchers have only recently started to look at the use of woody nitrogen-fixing plants (shrubs and trees) in soil fertility management and their application remains limited, especially in the HKH region. But shrubs and trees also have considerable potential for use in farming systems. For example Nepalese alder (Alnus nepalensis) stands of different ages were reported to fix between 29 and 117 kg nitrogen/ha/year (Sharma and Ambasht 1984, 1988) and these trees have multiple uses for farmers, including production of firewood and of animal fodder.

Rotation of nitrogen-fixing plants/crops with cereal plants

__Crop rotation__ is the practice of planting of crops and other plants one after another in a pre-defined sequence. Usually the crops and order of planting is designed both to make maximum use of different seasonal conditions and to maintain soil fertility by alternating inputs and removal of different soil components.

Rotational planting of nitrogen-fixing plants with other crops is a common practice in many parts of the world. The most common rotation cycle is planting of cereal crops followed by annual leguminous crops such as different types of peas and beans. The improvement in yield of cereals has been shown clearly in experiments: for example, wheat yield increased from 0.5 to 2.1 t/ha when planted after chickpea in experiments in Australia (Marcellos et al. 1993). Research carried out by the Australian Centre for International Agricultural Research (ACIAR) in Nepal and Pakistan indicates that rotation of leguminous crops like chick pea and faba bean can provide 24-35% of the nitrogen requirement for subsequent cereal crops (Lawrence 1999). Overall soil fertility is improved by rotation of perennial nitrogen-fixing plants and cereal crops.

Perennial woody nitrogen-fixing trees or shrubs can also be used in a crop rotation system. For example, in north-east India, south-west China, and some parts of Nepal, several species of alder (Alnus), especially Nepalese alder or utis (Alnus nepalensis), are planted on sloping rainfed land after two to three years of cultivation of cereal crops. The trees are then cleared, or in some cases pollarded or coppiced, after two or three years and used for fuel, and cereal crops are again grown. Or cereal crops are intercropped with alder while the alder trees are topped every year in order to avoid shading of the crops. In such a production system, soil fertility is improved and fuelwood is produced at the same time.

Intercropping of nitrogen-fixing plants/crops with cereal plants

Intercropping of nitrogen-fixing plants and crops with cereal crops is another common practice. Usually different types of peas or beans are planted together with corn or wheat. Perennial nitrogen-fixing plants can also be used in this type of system. Experiments on intercropping of leucaena or ipil-ipil (Leucaena leucocephala) with corn in South America showed the yield of corn to be almost the same or slightly higher than the yield without intercropping. At the same time, between 9 and 18t/ha of fresh biomass (green manure), 80-90 kg/ha of nitrogen, 6 to 8 kg/ha of phosphorous, and 45 to 50 kg/ha of potassium was added to the soil during the four-month intercropping period, ensuring that soil fertility was maintained for the next growing season (Rachie 1983).

Intercropping (or companion planting) is the practice of planting of two or more crops and/or other plants together in a complementary system, typically as alternating rows or numbers of rows. Usually plants are chosen that benefit each other in some way, for example protection from pests or the elements, provision of nutrients, weed suppression, or structural support; and/or that help minimise farmers' risks by ensuring that whatever the conditions at least a part of the crop will be harvested. The system is more labour intensive as the crops must be separated during harvesting. Intercropping is widely used in traditional integrated farming methods in the HKH region.

Intercropping of nitrogen-fixing alder (Alnus) and albizia (Albizia) trees with cash crops such as large cardamom (Amomum subulatum) and mandarin orange (Citrus reticulata) is found in traditional agroforestry systems of the Eastern Himalayas. Alnus was reported to fix 65 kg nitrogen/ha/year and increase crop yield of cardamom 2.5 times compared to stands without nitrogen-fixing associates; Albizia fixed only 3 kg nitrogen/ha/year and increased mandarin fruit yield by 20% (Sharma et al. 1994, 1995).

Cereal crops like maize and wheat are harvested each year, leading to a loss in nutrients from the soil. If these are not replaced, soil fertility and soil organic matter will decline, which leads in turn to a decline in yield of successive crops and an increased risk of soil erosion. A change from monocropping of cereal crops to intercropping with leguminous crops would lead to a more productive and sustainable system and help prevent a further decline in soil fertility. However, it is important to select nitrogen-fixing plant species appropriate for the particular location in order to achieve the maximum benefits of nitrogen fixation. For example, beans are poor fixers of nitrogen in semi-arid climates and are thus less suitable to use for intercropping in such areas; cowpea fixes more nitrogen under these conditions and is more suited for use.

Green manure

Green manure is a growing cover crop of annual plants (or other growing plant material) that is dug into the soil to improve or restore fertility and soil texture. These plants are generally grown on fallow land and then dug into the soil before crops (or ornamental plants) are planted, although in some cases plants are grown in one place and the foliage and roots dug into the soil or used as mulch material in another.

Cultivation of green manure is an important practice in soil fertility management. Green manure can be cultivated after the harvest of corn, rice, or other cereal crops. Leguminous green manure crops can provide a biomass of around 28,000 to 48,000 kg/ha (dry matter), with root residues providing as much as 1,900 to 3,300 kg per ha, with an average of 2,400 kg/ha (dry matter) or 12-20% of the total biomass of the green manure crops (Zhou 1995). The total yield of green manure of some medic species (Medicago) can be as high as 36,750 kg per ha per season (Zhou Chunlai 1995). Many green manure plants can also be used as fodder for livestock, especially in the dry season, and some leguminous green manure crops provide other direct benefits like faba beans or peas for food.

Large cardamom intercropped with nitrogen-fixing alder trees

Planting and use of green manure improves both the chemical fertility and the physical properties of soil, and enhances subsequent crop yields. The effect is greater when the green manure is incorporated into the soil. In an on-farm study in Shanxi Province in China, planting of alfalfa (Medicago sativa), wild vetch (Vicia sp.), or milk vetch (Astragalus adsurgens) on sloping cropland during a fallow period of three months increased wheat yields by 68.5, 58.6, and 49.3%, respectively (Chen Naizheng 1984).

The roots and fallen leaves of leguminous crops can also be used as green manure and can make an important contribution to soil fertility improvement. A study in Tibet, China, indicated that leguminous crops provided around 5,800 kg/ha of roots and fallen leaves, with a soil improvement effect equal to 3,000 to 4,000 kg/ha of farmyard manure (Zhou Chunlai 1995).

Some tree leaves can also be used as green manure. For example, the fresh leaves of long peduncled alder

(Alnus cremastogyne) contain 3% of nitrogen. Farmers in the Yanting County of Sichuan Province in China use the green leaves as green manure in their paddy fields. Adding around 9.8 t/ha of fresh leaves can effectively improve soil fertility leading to a 15-20% increase in rice yields (Deng and Liu 1987). As with other nitrogen-fixing plants, however, species appropriate for use in one area may not be in another: these trees didn't grow well in other regions with a different climate.

In remote rural regions, where chemical fertiliser is unobtainable or too expensive, growing nitrogen-fixing plants for green manure may prove attractive and practical. For example, cultivation of green manure (Vicia villosa var. glabrescens) is a common soil fertility management practice in many apple orchards in Maoxian County of Sichuan Province in China.

Contour hedgerows of nitrogen-fixing plants

Growing crops between hedgerows of nitrogen-fixing plants is a relatively new practice in the HKH region. In this system, nitrogen-fixing plants are planted very thickly along the contour lines of sloping land. The thickly planted hedgerows act as an effective barrier to soil erosion, with washed down soil collecting behind them to form terraces, and improve soil fertility through addition of fresh leaves (hedge clippings) as green manure or mulch material and decayed roots and leaf litter. The practice is generally referred to as sloping agricultural land technology (SALT) or contour hedgerow intercropping agroforestry technology (CHIAT).

Mulching is the practice of spreading organic matter like leaves, grass cuttings, straw, bark shavings, compost, or other plant residues on the bare soil between and among crop or ornamental plants. The layer helps reduce evaporation, thus increasing moisture availability, hinders growth of weeds, and increases soil fertility as the mulch layer decays and the released nutrients enter the soil.

Contour hedgerows of nitrogen-fixing plants have proven effective in improving the soil fertility of sloping agricultural lands and preventing degradation of such farmland (Sun Hui et al. 1999a; Tang Ya et al. 2001). The hedgerow clippings are rich in nitrogen as well as containing other nutrients like potassium and phosphorous. For example, in one study dry leaves of Mexican gliricidia (Gliricidia sepium) were found to contain 3-4% nitrogen and 3.5% potassium, and leaf litter and fresh leaves from a coralbean species (Erythrina poeppigian) to contain 2.3-3.6% and 4.1-4.9% of nitrogen, respectively (Glover 1986; Nygren and Ramirez 1995). Our own work indicates that the foliage of ipil-ipil (Leucaena leucocephala) contains about 4% nitrogen. Even more important, the addition of hedgerow clippings to the soil increases the soil humus and organic matter content, which considerably improves the soil physical properties.

Contour hedgerows of nitrogen-fixing plants not only provide nutrients for the growth of the companion crops, they can also improve the supply of phosphorous and potassium from deep layers of the soil through their deep root systems. A series of field studies carried out in Nepal indicated significant loss of soil nutrients through leaching (Gardner 2000). Establishing deep-rooted hedgerows of nitrogen-fixing plants provides a means of recapturing the nutrients lost by leaching and recycling them via the hedgerow clippings.

Mixed forests

Monoculture forests are now widely recognised to be unsustainable in terms of their stability and ecological function. These days, mixed forests are often recommended and promoted for afforestation and reforestation programmes. Including nitrogen-fixing trees in mixed forests offers several benefits, the major one being the addition of nitrogen to the soil, which improves soil fertility and helps improve the growth of the companion trees. Both the root nodules and the fallen leaves of the trees contribute to the nitrogen enrichment of the forest soil.

Using nitrogen-fixing plant species in mixed forest plantations can have an immediate impact followed by a steady improvement thereafter. In a seven-year study, planting of seabuckthorn (Hippophae rhamnoides) with willow (Salix matsudana) and poplar (Populus sp.) was found to increase soil nitrogen content from the first year of planting; the nitrogen fixed by the root nodules increased considerably with time (Table 4) as did the nitrogen returned to the soil by leaf litter (Table 5).

Table 4: Nodule biomass and fixed N in mixed forest with seabuckthorn (***H. rhamnoides***), kg/ha/year

	Tree age in years						
	1	2	3	4	5	6	7
Nodule biomass	46	236	347	425	486	536	575
Fixed N	3.7	20.4	49.0	66.3	72.3	79.3	84.8

Source: He et al. 1996

Table 5: Nitrogen returned to soil from fallen leaves of seabuckthorn (***H. rhamnoides***), kg/ha/year

	Tree age in years				
	1	2	3	4	5
Biomass of fallen leaves	591	2513	5,571	10,283	14,667
N returned to soil	12	50	111	206	293

Source: He et al. 1996

Nitrogen-fixing plants also support tree growth through improvement of soil organic matter. Planting of seabuckthorn (Hippophae rhamnoides) with poplar and willow was found to increase soil organic matter by 37-42% and nitrogen by 20-22% compared to the values in soils of a monoculture plantation and led to improved growth of the companion trees (He et al. 1996). Similarly, topsoil organic matter was enhanced by 40-60% under canopies of auriculate acacia (Acacia auriculiformis) and lebbek albizia (Albizia lebbeck) compared with grass fallow (NAS 1979).


Alnus trees in the background of a mixed forest area on a previously degraded slope

Soil conservation

Particularly in developing countries, the demand to use sloping agricultural lands to grow crops is increasing as populations grow and flatter agricultural land is lost for production as a result of land degradation, infrastructure construction, urbanisation development, and others. However, using sloping land for crops can lead to considerable problems including serious soil and nutrient loss as unprotected soils are washed down the slopes, with a resultant rapid decline in soil fertility, and mudslips and landslides where the slopes are destabilised. The most common and effective method used for soil conservation and fertility management of sloping agricultural land is the construction of bench terraces. In many countries of the HKH, terracing has played a very important role in controlling soil loss and improving land productivity – but there are limitations. These include the large investment in construction and maintenance, instability, and the fact that sandy and coarse textured soils cannot be terraced without support.

Establishing hedgerows along contour lines can help to overcome these problems, particularly if nitrogen-fixing species are used (Partap and Watson 1994; Tang Ya 1999; Tang Ya 2004). The systematic placement of the hedgerows reduces soil loss to an extremely low level and stabilises the slopes. Soil washed from below one line of hedgerows is deposited behind the next lower line, eventually leading to the formation of a terrace between the two hedgerows - a so-called 'bioterrace'. The terraces develop naturally so no labour is required for terrace construction. The aggressive taproot system of the hedgerow plants helps break up compacted subsoil layers, which improves the penetration of moisture into the soil and decreases surface runoff. Our experience shows that in very degraded soil the surface runoff from the plots with hedgerows is less than half (37-47%) of that from traditional sloping farmland (Tang Ya 1998; Sun Hui et al. 2001). Reduction of soil loss is even more impressive. In the tropics of Africa and the Philippines, investigations showed that soil loss with contour hedgerows is only 1.6-2.7% of that from land kept according to traditional farming practices (Kiepe 1995; Palmer 1996); in a study in the HKH region, soil loss was reduced by 90-99% 2-5 years after contour hedgerows were established (Sun Hui et al. 1999b). Compared with the conventional bench terrace, the bioterrace with nitrogen-fixing species has numerous advantages, including low investment, increased stability, ability to improve soil fertility, applicability in almost all types of soil, and provision of fodder and or fuelwood by the hedgerow plants.

Another important method for using nitrogen-fixing plants for soil conservation is planting of cover plants. Many herbaceous legumes can be planted as cover crops both to improve soil fertility and to conserve soil because cover crops can shield the soil surface from erosion by water and wind (Qi et al. 1998).

Rehabilitation of degraded land

Clearance of forests and other types of vegetation for agriculture in the mountains is thought to be one of the major causes of soil erosion. The combined result of vegetation clearance and soil erosion has led to the development of large areas of wasteland. In the upper reaches of the Yangtze River, for example, wasteland covers an area of 11 million hectares. Efforts to rehabilitate degraded mountain ecosystems generally focus on afforestation and reforestation. However, as a result of the severe and continuous soil erosion in these areas most of the fertile topsoil has been washed out; the soils are usually very low in nutrients and have very poor properties. Planting of trees, especially timber trees, has often been unsuccessful. Such failures may have various causes, but the use of inappropriate species is likely to be an important one. Many plants are difficult to establish in degraded and infertile habitats. However, many of the nitrogen-fixing plants can grow in the most barren terrain as they provide their own nutrient nitrogen.

Nitrogen-fixing plant being used to rehabilitate highly degraded land

There are many nitrogen-fixing plants that have the ability to thrive on poor soils and in areas with long dry seasons and can thus be used for initial planting on bare ground, wasteland, or sand dunes. For example, Acacia colei has rapid early growth even under difficult conditions. If it is planted during the monsoon season, it is hardy enough to withstand the subsequent drought and can thrive on wasteland. Similarly, high biomass production has been obtained from auriculate acacia (Acacia auriculiformis) on very poor lateritic soils where many other trees will not grow (NAS 1979). Similarly, bayberry (Myrica) is deep-rooted and can grow in acidic soil; its nitrogen fixation capacity (0.4g/growing day) during the growing season is higher than that of soybean (0.25g/ growing day) and it is also an important fruit tree in many areas to the south of the Yangtze River in China. It is used as an important species for restoration of degraded acidic soils in Southwest China. Alder (*Alnus nepalensis*) is used for stabilising and restoring landslide affected sites in the HKH region because of its efficiency in nitrogen fixation and fast growth (Sharma 1988).

Once established, nitrogen-fixing plants can create conditions that induce other species to grow well. Thus they act as pioneers, preparing difficult sites for farming or forestry. Many nitrogen-fixing plants could be prime candidates for restoring forest cover to watersheds, slopes, and other lands that have been denuded of trees. Successful examples are common.

The projects carried out by ICIMOD on rehabilitation of degraded land in the middle hills of Nepal, and on appropriate technologies for soil conserving farming systems in southwest Sichuan Province of China have shown that legumes such as white tephrosia (Tephrosia candida) and ipil-ipil (Leucaena leucocephala) grow very well on very eroded soils where no other plants will grow. In Ningnan County in southwestern China, scientists from the Chengdu Institute of Biology of the Chinese Academy of Sciences showed that planting of nitrogen-fixing plants can considerably improve soil condition (Table 6). The soil moisture of plots planted with eucalyptus and legumes was 7-8% higher than that of the bare land; soil organic matter in plots planted with nitrogen-fixing legumes was 30-80 % higher than that of the bare land, and 1-40% higher than that in plots cultivated with longbeak eucalyptus alone (Eucalyptus camalduensis); and the total nitrogen of plots cultivated with eucalyptus and nitrogen-fixing plants and or nitrogen-fixing plants alone was 6-35% higher than that of the bare land plot and the plot with longbeak eucalyptus alone (Eucalyptus

Table 6: Contents of soil moisture, organic matter and total nitrogen of surface soil (0-20cm) under cultivation with different plants (%)

	Ec+Cc	Ec+Ll	Ec+Tc	Ll+Tc	Ll	Tc	Ec	Bare land
Soil moisture	6.38	6.38	6.46	6.42	6.46	6.46	6.26	5.97
Soil OM	0.83	0.99	1.01	0.90	1.15	1.13	0.82	0.64
Soil N	0.072	0.082	0.086	0.092	0.092	0.09	0.068	0.068

Ec: *Eucalyptus camaldulensis* (not nitrogen fixing); Cc: *Cajanus cajan* (leguminous); Ll: *Leucaena leucocephala* (leguminous); Tc: *Tephrosia candida* (leguminous); OM: organic matter; N: nitrogen.
(Source Chen et al.1991)

camaldulensis) (Chen et al. 1991). In another study, lespedeza (Lespedeza sp.) was shown to be very successful in rehabilitating very degraded red soil in Jiangxi in China (Wang et al. 1993).

Woody fodder

There is considerable competition for land both for different agricultural and other uses, and there may not be enough good land available to produce the amount of fodder estimated to be necessary in plans for livestock development. Fodder production can be increased by improving the productivity of fodder crops and through scientific management of permanent pasture and grazing lands, but this may still not be sufficient. Another important possibility is to increase the amount of woody fodder – leaves from trees and shrubs – grown in agricultural areas.

Grasses die back when the upper layers of soil lose their moisture, but tree roots exploit deep underground moisture, and during the dry season trees and shrubs can provide green fodder. Woody fodder is an important basis for livestock development in areas with a long dry season. Development and use of woody fodder is common in South Asia including the southern areas of the Himalayas, but is very rare in the Himalayan region of China. Many of the woody fodder species used in the HKH region are leguminous nitrogen-fixing species like sissoo rosewood or sissoo (Dalbergia sissoo), prickly acacia (Acacia nilotica), purple bauhinia (Bauhinia purpurea), Buddhist bauhinia (Bauhinia variegata), and lebbeck albizia (Albizia lebbeck), although some non-nitrogen fixing woody plants, like opposite-leaf grewia (Grewia opptiva) and fig trees (Ficus spp), are also used. Leguminous tree fodder has a higher content of crude protein and calcium than grasses and non-legumes, while other nutrients are more or less similar (Table 7). Development of trees for fodder can be combined with wasteland reclamation. This approach has the added advantage of providing direct benefits to the local people during the course of rehabilitation of wasteland. Previous failures in wasteland development may sometimes have resulted from the more timber-oriented reforestation approach used, and lack of consideration of local needs. The HKH region is rich in legume diversity. There is a very bright prospect for the development of woody fodder in the region.

Withered leaves from young *Leucaena* trees provide fodder for pigs

Table 7: Nutrient composition of some common fodder plants (% of absolute dry matter)

Plant species	Crude protein	Crude fat	Crude fibre	Crude ash	N-free extract	Ca	P
Grasses/non-legumes							
Non-woody							
Setaria vividis	12.1	2.0	26.5	13.8	45.6	0.43	0.33
Pennisetum flaccidum	9.6	2.3	20.0	9.4	58.7	0.25	0. 29
Arthraxon prionodes	7.2	2.0	32.5	9.6	48.7	0.86	0.18
Digitaria cruciata	14.2	2.2	26.4	14.5	42.7	0.50	0.38
Eragrostis ferruginea	9.7	2.3	35.9	7.4	44.7	0.49	0.09
Andropogon yunnanensis	11.6	2.3	30.7	11.5	43.9	0.31	0.23
Tripogon filiformis	10.1	2.2	34.8	11.5	41.4	0.70	0.14
Mariscus umbellatus	8.9	1.4	30.1	10.4	49.2	0.47	0.30
Woody							
Grewia optica	17-20		19-22	10-14	42-49	2.7-3.6	0.14-2.24
Celtis australis	14-15		20	12-18	45	3.5-4.9	0.18
Legumes							
Non-woody							
Lespedeza dahurica	16.1	1.8	31.7	7.4	43.0	1.42	0.24
Kummerowia striata	14.8		26.0	11.9	45.9	1.37	0.18
Woody							
Sophora viciifolia	22.5	2.9	8.9	6.8	48.9	1.06	-
Bauhinia fabri	21.3	4.0	18.9	7.0	48.8	1.31	0.30
Indigofera bungeana	17.3	2.2	32.8	7.2	40.5	1.40	0.21
Campylotropis poliantha	17.1	3.5	25.0	7.8	46.6	1.84	0.17
Campylotropis sp.	10.4		43.2	4.1	39.6	0.72	0.15
Acacia sp.	19.6	1.6	23.9	6.7	47.9	1.37	0.15
Acacia nilotica	14-20	2.7	6.5-33.3	4.8-11	51-70	1.8-4.1	0.21
Bauhinia variegate	11-16	1.9	25-33	–	–	1.8-4.1	0.2-0.4
Dalbergia sissoo	17		22	9	49	–	0.2-0.4
Leucaena leucocephala	20		10-17	5-10	50	3	0.2

(Sources: CIB and SPGI 1984; Parkash and Hoching 1986)

Crops for firewood

Fuelwood from trees or shrubs is an important basic requirement for mountain people. It is not only needed for cooking, it is also needed for heating in winter. In 1980, it was reported that more than 1.5 billion people in developing countries derived at least 90% of their energy requirements from wood and charcoal. Another billion people met at least 50% of their energy needs this way. A brief survey of the current literature indicates that this situation has changed little during the past two decades. The annual fuel requirement per family in the Himachal of India was estimated to be around 18 tonnes on average: 14 tonnes at low elevation, 19 tonnes at mid elevation, and 26 tonnes at high elevation (Swarup and Tewari 1988). It is estimated that at


Pruned nitrogen-fixing contour hedgerow on a previously degraded slope

least half the timber cut in the world still serves its original role for mankind as fuel for cooking and heating (National Academy of Sciences 1979). A recent survey in the Tibet Autonomous Region of China revealed that over one third of the trees cut in the past four decades were used as fuel.

Collecting fuelwood is a very important activity for mountain people. Wood is most commonly collected from – fast-depleting – forests; and this is a major problem for forest conservation. There are many woody nitrogen-fixing plants that grow fast and have a high heat value and are thus excellent sources of fuel, and there are various possibilities for growing such trees and woody plants to help meet the fuel requirement.

In degraded mountain areas, forests of nitrogen-fixing plants can be managed to produce both fodder and fuelwood. Once the soils have improved, cash crops can also be cultivated under the trees. Fast growing nitrogen-fixing trees, both legumes and non-legumes, can also be planted on marginal lands. These trees protect and improve the soil on the one hand, and provide fuelwood to the farmer household on the other. For example, planting of siamese senna (Cassia siamea) for fuelwood is a common practice in southern Yunnan of China, Myanmar, and Thailand. Ipil-ipil (Leucaena leucocephala) can produce 15-22t dry fuelwood per hectare per year; our work in Ningnan, China, indicates that silver wattle (Acacia dealbata) can grow up to 4-5 metres in three to four years.

In the HKH region, planting of nitrogen-fixing plants to supply fuelwood can contribute considerably to the conservation of forests. Selection of species suitable for deliberate cultivation as fuelwood in developing countries will be an important and useful task for the future.

Use of terrace risers

Terraces are one of the most striking landscape features in the HKH region, but usually no use is made of the terrace risers. There are considerable advantages to be gained from planting nitrogen-fixing plants on terrace risers. They can produce fuelwood and fodder, help to maintain soil fertility, and can help to stabilise risers which may otherwise collapse. The plants can also be used to make compost or used directly as green manure or mulch material, and can provide raw materials for household enterprises such as basketwork, which can contribute to household income generation. The Indian Council of Agricultural Research is testing the use of terrace risers to grow fodder grasses at its Northeast Complex; these plants have a two-fold function, namely, providing fodder and stabilising the risers. If nitrogen-fixing plants are planted this can add a third function of fixing nitrogen.

It is important to select the proper species for planting on terrace risers: the nitrogen-fixing plants should not be trees but rather small shrubs with erect stems, subshrubs, or herbaceous species such as indigobush (Amorpha fructicosa), erect milk vetch (Astragalus adsurgens), and alfalfa (Medicago sativa). More needs to be done to identify the most appropriate species for different agro-ecological zones.

Other uses and applications

Nitrogen-fixing plants can be managed for other uses in addition to those discussed above. Many nitrogen-fixing plants produce good food. People are familiar with annual leguminous crops like peas and beans, but there is less awareness of the food potential of some woody and perennial legumes. The seeds of some Acacia species that have shown promise in planting programmes in semi-arid areas are a traditional part of the diet of Australia's Aboriginal people. The green seed pods can be eaten raw or cooked in ashes; the dry seeds can be ground to flour, mixed with water, and eaten as a paste or baked to form a cake. Legumes can also be managed to produce gums and tannin. For example, black wattle (Acacia mearnsii) is a good candidate for tannin production. Fast growing nitrogen-fixing plants can also be managed as paper pulp forest. For example, a planting density of 10,000 plants/ha of common sesban (Sesbania sesban) can produce 15-20 tonnes of dry matter per annum.

From a botanical point of view, the leguminous family is second only to the grass family in terms of the number of useful plants it contains. However, compared to the grass family from which many important crops are derived, only a few legumes are being used as food crops, soybean and peanut being among the most important. There is a rich variety of legumes in the subtropics and tropics, but only about 20 species are used widely, which indicates that there are a great number of species left to be exploited. Legumes are important sources of protein, and many beans are used in cooking in south Asia and Africa.

Replace photo???

Chapter 3

Conclusions

In order to accommodate the world's expanding population, the production of food crops must increase continuously. As there is only a limited amount of suitable new land, the increase will have to be achieved primarily by increasing the productivity of currently farmed areas, preventing degradation of farmland, and using previously degraded land and land previously not used, for example sloping land. Nitrogen-fixing plants have a great potential for improving soil fertility, soil conservation, rehabilitation of degraded wasteland, and stabilising and improving sloping land. With appropriate management, these plants can also provide fodder and fuelwood, thus reducing the pressure on forests, and also food itself. Promoting the use of nitrogen-fixing plants will contribute considerably to sustainable mountain development and should have a high priority in development programmes.

Any increase in the use of nitrogen-fixing plants in agriculture and forestry will lead to a clear reduction in the application of chemical fertilisers, thus reducing production input costs as well as the negative impact of chemical fertilisers on the environment.

The key factor for the successful application of nitrogen-fixing plants is the use of appropriate species. Selection of nitrogen-fixing plant species is therefore a key step; the choice for a specific location and use can be limited. Finding the most appropriate niche for nitrogen-fixing plants in the various agricultural, horticultural and forest systems is a real challenge. For certain localities, selection of appropriate nitrogen-fixing plants is not easy. Different species have their own preferred conditions for growth and development. Species suitable for site A may not be suitable for site B. However, there are several thousands of nitrogen-fixing plants in the natural systems in the HKH region. If the appropriate research is conducted, it should be possible to find suitable plants for specific localities in any agro-ecological zone. Indigenous nitrogen-fixing plants will have the advantage of suiting local conditions. Selection of local or exotic species should be made through field experimentation in different agro-ecological zones.

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About the Authors

Tang Ya is currently Professor of Environmental Biology & Ecology at the College of Environment, Sichuan University, China. He received his doctorate in 1990 from the Kunming Institute of Botany, Chinese Academy of Sciences, after which he joined the Chengdu Institute of Biology, Chinese Academy of Sciences, where he was promoted to research professor within five years, becoming one of the youngest professors in China, and served as Deputy Head and Head of the Department of Botany and Ecology. He worked at ICIMOD from July 1995 to December 2001 as project coordinator, agroforestry/soil conservation specialist, and then Head of the Mountain Farming Systems Division, before rejoining Chengdu Institute of Biology as professor and Chairman of the Academic Committee, before joining Sichuan University in 2003. He has published widely, with around 100 papers and book chapters credited to his name, and during the course of his career has been elected to the boards of a number of professional societies and science journals. His current research interests include the systematics and biogeography of the order Malvales, the pollination of *Pedicularis* and the impact of environmental changes on biodiversity. He can be contacted at <tangya@cib.ac.cn>.

International Centre for Integrated Mountain Development
Khumaltar, Lalitpur, GPO Box: 3226, Kathmandu, Nepal
Email: distri@icimod.org.np Website: www.icimod.org
Telephone: 977 1 5525313 Fax: 977 1 5524509/5536747
Godavari Site Telephone: 977 1 5560289

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