Chapter 3

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

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INTRODUCTION

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

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

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

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

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

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

Materials and Methods

Study site

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

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

Experimental design

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

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

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

Sampling

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

Chemical analysis of soil samples

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

Biomass production of hedgerows

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

Crop yield

The total crop yield was recorded for each plot.

Statistical analysis

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

RESULTS

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

Table 3.1: Initial chemical properties of the soil

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

Table 3.2: Percentage of soil particles of different size

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

Changes in chemical fertility

Soil acidity

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

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

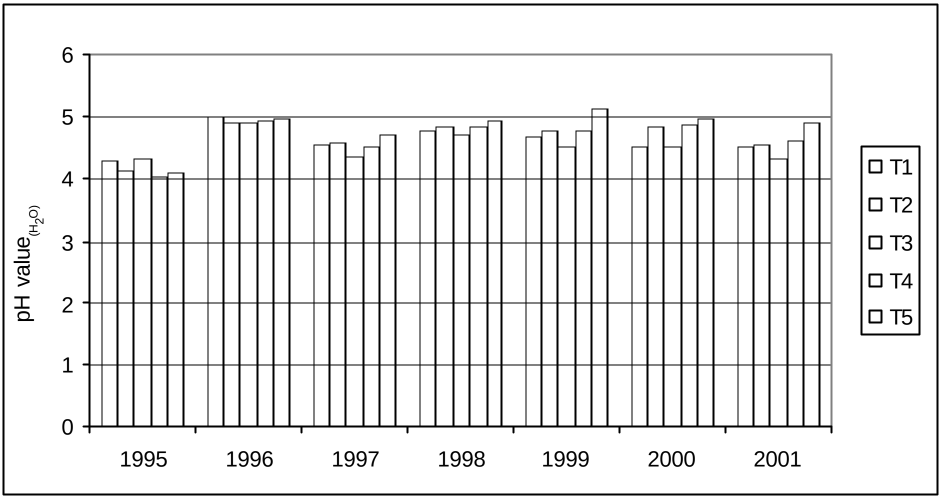

Figure 3.1: Soil active acid

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

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

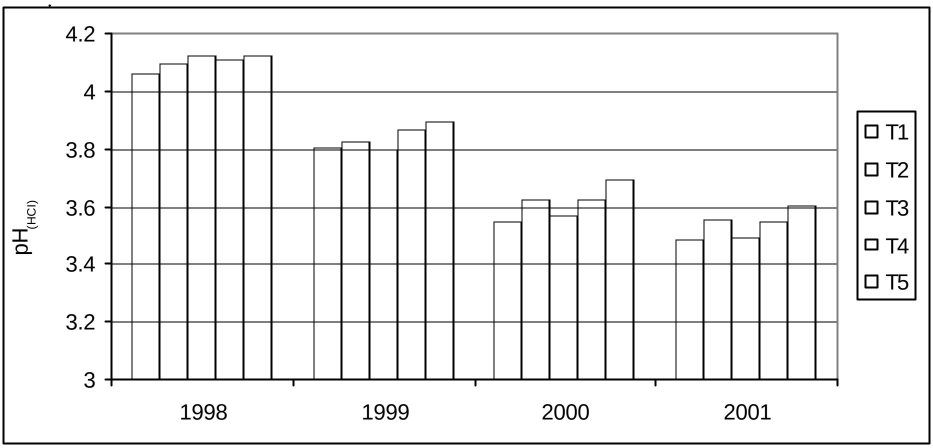

Figure 3.2: Soil potential acid

Soil organic matter

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

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

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

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

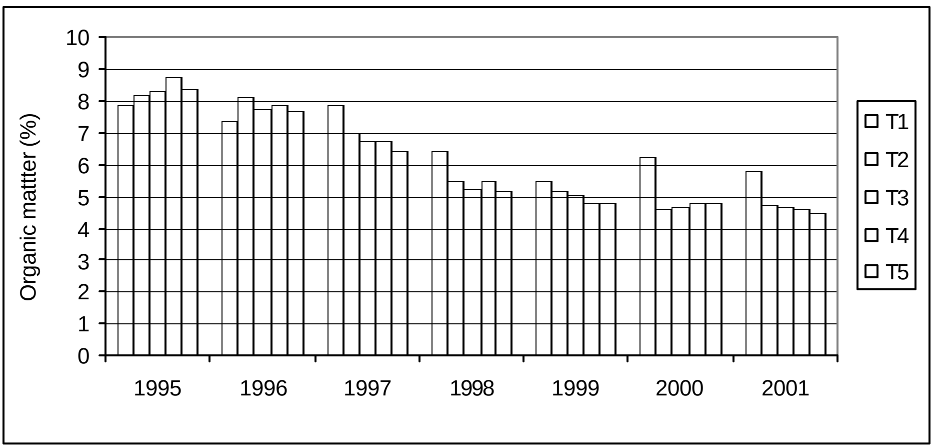

Figure 3.3: Soil organic matter

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

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

Total nitrogen

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

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

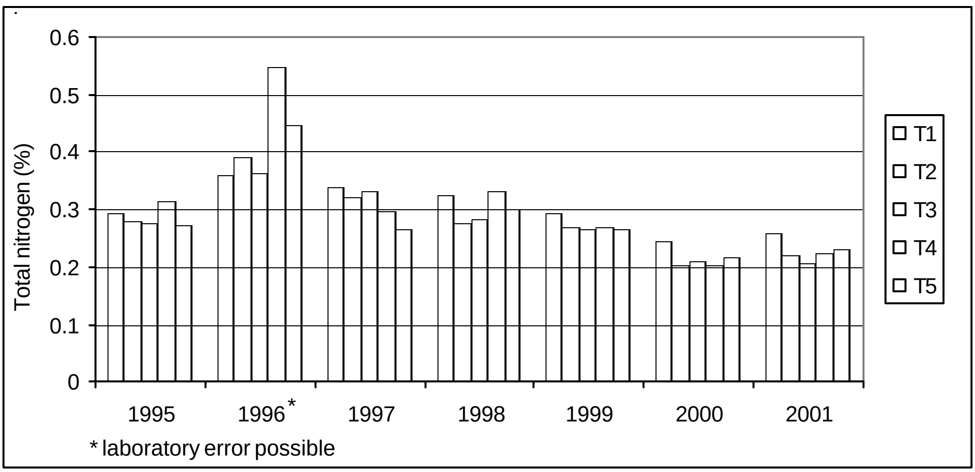

Figure 3.4: Soil total nitrogen

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

Available phosphorous

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

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

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

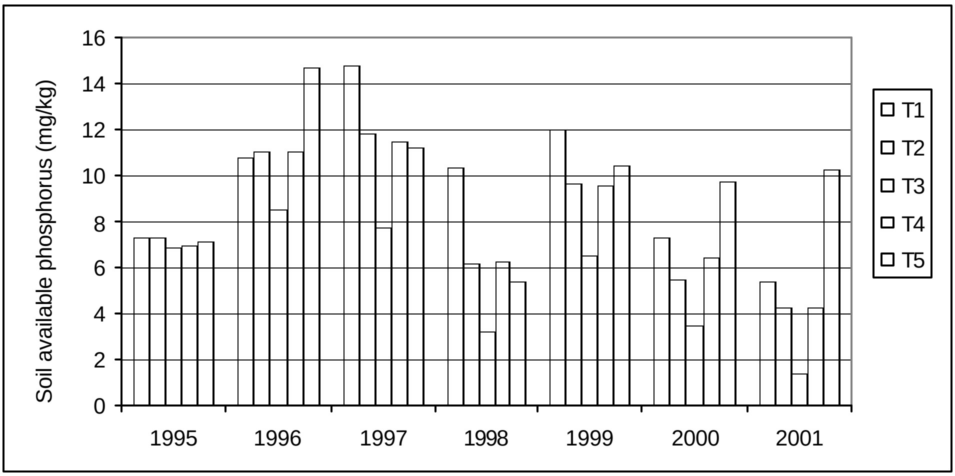

Figure 3.5: Soil available phosphorus

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

Available potassium

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

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

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

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

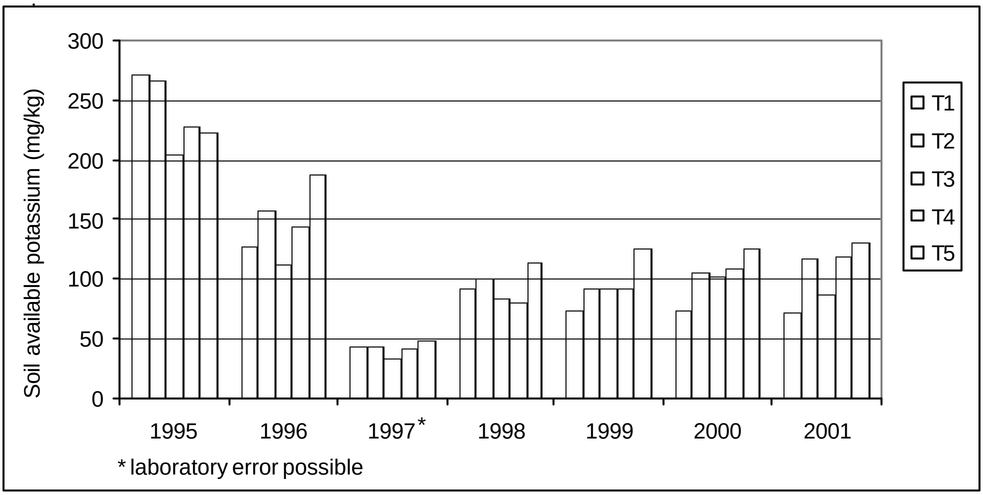

Figure 3.6: Soil available potassium

Effective cation exchange capacity (ECEC)

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

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

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

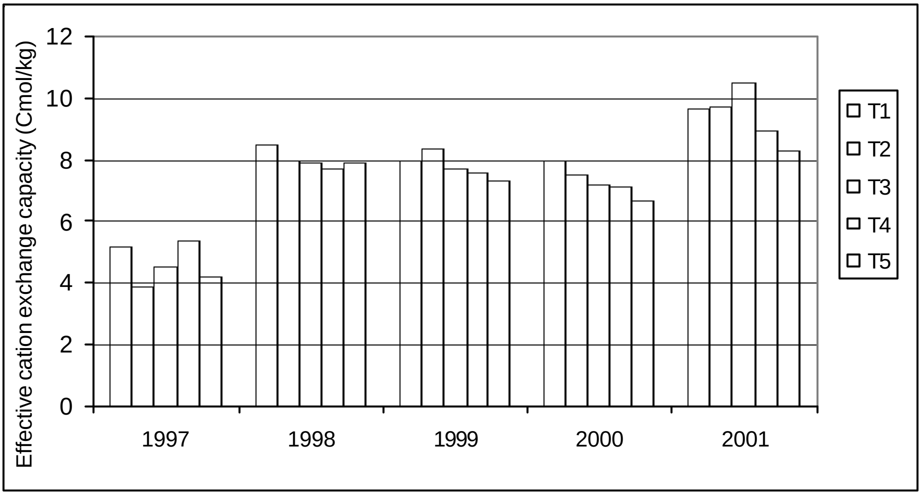

Figure 3.7: Soil effective cation exchange capacity (CEC)

Exchangeable calcium

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

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

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

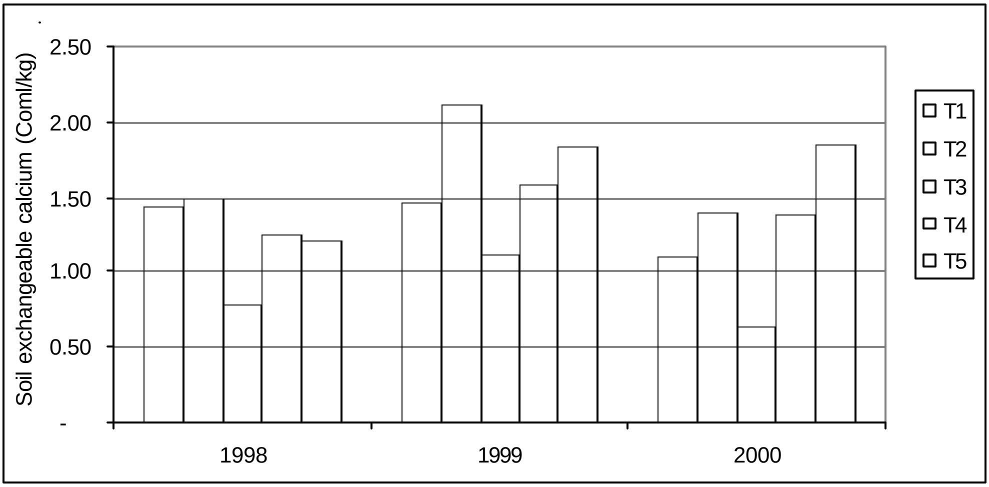

Figure 3.8: Soil exchangeable calcium

Exchangeable magnesium

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

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

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

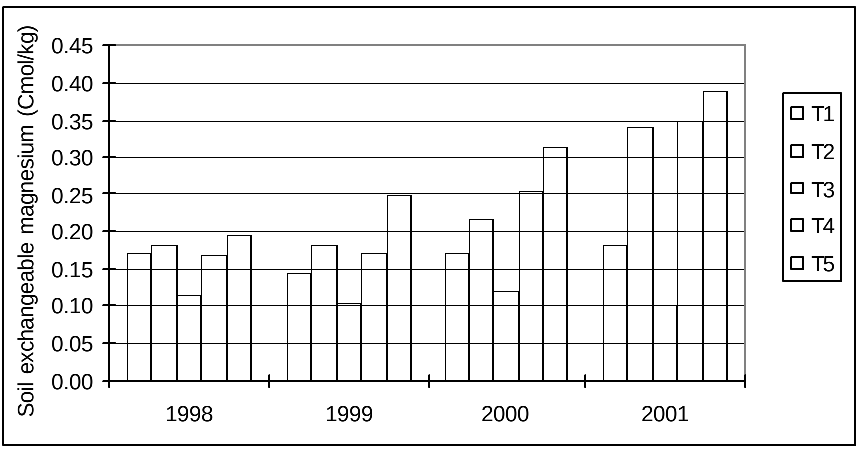

Figure 3.9: Soil exchangeable magnesium

Exchangeable sodium

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

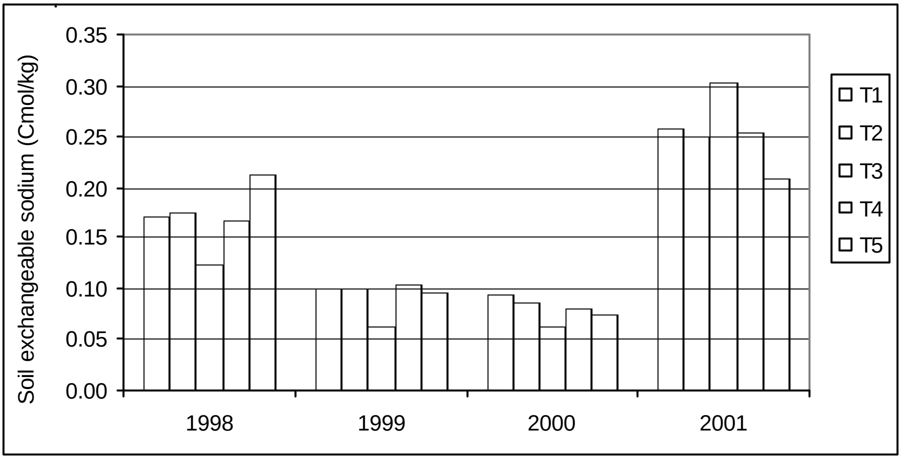

Figure 3.10: Soil exchangeable sodium

Exchangeable potassium

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

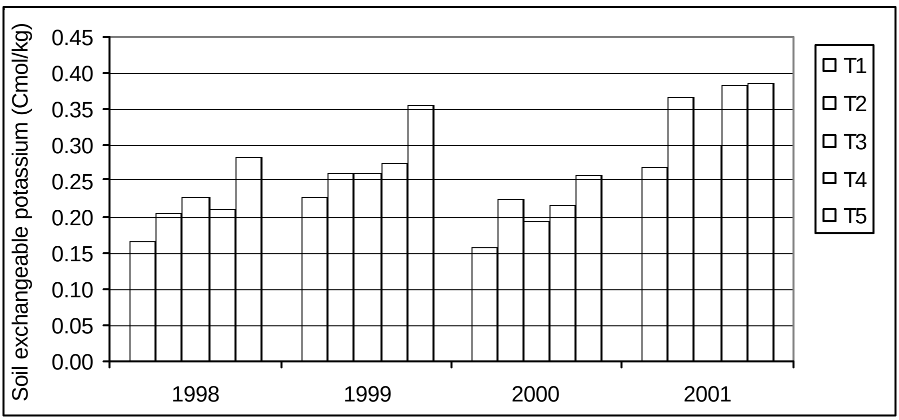

Figure 3.11: Soil exchangeable potassium

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

Biomass production of hedgerows

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

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

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

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

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

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

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

Crop yield

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

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

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

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

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

Discussion

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

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

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

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

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

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

Conclusions

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

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

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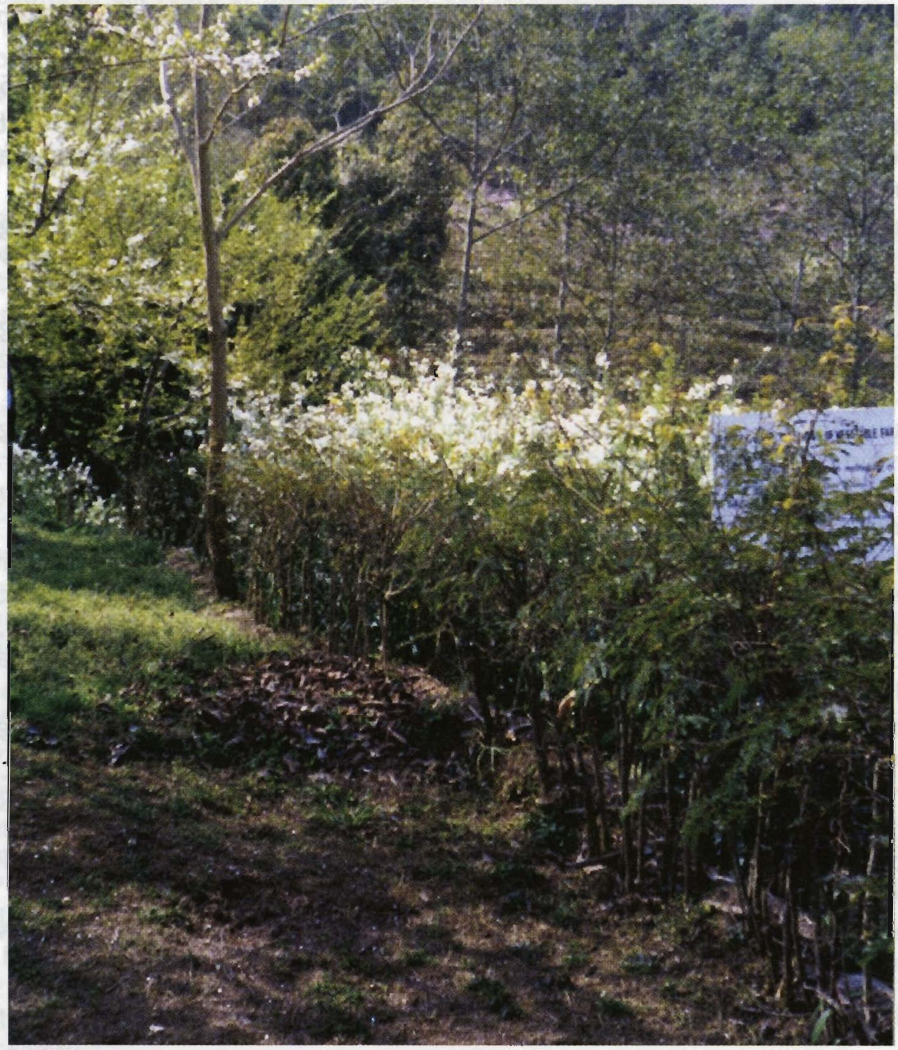

Part of a terrace formed by planting of hedgerows of nitrogen-fixing plants. It is similar to the control plot – without crops – used in the nutrient competition studies described in the next chapter.