- More horticulturists, anthropologists, and ethnobotanists, and above all, local people should be consulted in species selection and testing.
- There is a need to expand the evaluation of germplasms through networking, concentrating on edaphic and management variables, etc., and to develop genetic improvement strategies and selection objectives for the poor. International exchange of information and seeds is important. Local networking and banks of local planting material deserve even greater support.

Establishment and management:

- The further development of cost-efficient and affordable planting and management techniques on difficult sites should be one top priority of research and development.
- Multi-purpose hedges on marginal sites deserve special attention in monitoring nutrient cycling including N-fixation, total nutrient budget, mineralization rates, and root interaction.
- More research is needed into the establishment of hedgerows by cutting and direct seeding. In particular, a comparison of seeds and stake establishment is required.
- The management/hedgecrop interaction needs to be further studied in specific agroforestry land uses.
- In extension and land-use planning more emphasis has to be given to how to protect young hedges.
- More research is required into harvesting techniques like pollarding, lopping, and multi-purpose management.
- More research is required into optimum timing, frequency and cutting height of pruning in representative agro-ecological zones for specific uses. More often than not there may be a need to depart from the general tendency to maximise biomass and other outputs.

International cooperation and future action program:

- The organisation of an international workshop on hedges for rural development, bringing together all persons concerned (scientists, planners, field workers), is an important next step.
- Feedback from the field of this publication and the pragmatic workshop and updating hedgerow activities (beginning in 1989) should be used as major inputs for the development of a manual on hedges.
- Technical cooperation between developing countries (TCDC) is recommended. Regional cooperation with regard to hedgerows should focus on information exchange, training, research, and demonstration.
- Networking should be fostered. Instead of creating a specific network for hedges, an alternative suggestion is that an informal lobby should develop a strategy for integrating hedgerow messages in relevant networks.

3 USES AND FUNCTIONS OF HEDGES

A hedge is not a substitute for a fence, it can offer much more. Hedges can serve all social groups. The potential role of hedges differs from one group to another: rich and poor, urban and rural. Chapter 3 is the core of the hedge book. Uses of hedges and specific targets to achieve are the theme of this chapter. The discussion of specific uses of hedges will show the whole range and complexity of the multidimensional aspects of utilisation. For more general technical aspects see Chapters 5 and 6. The perspective of the resource-poor land users is the main reference base (for more details consult Chapter 4). The bias is towards rural areas. The fact that in the near future half the human race will live in urban areas indicates future tasks for hedgerow research and development.

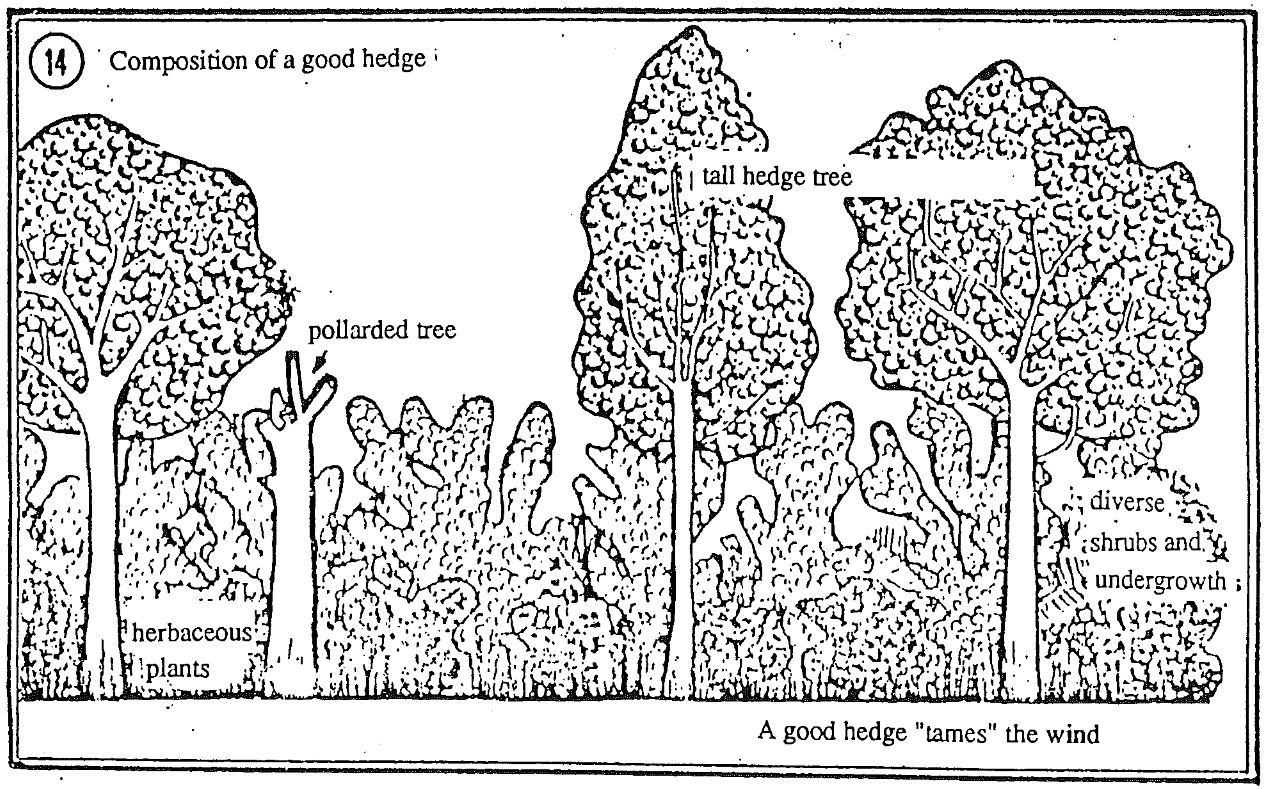


Figure 6: Example of a multipurpose hedge for resource-poor land users (98)

3.1 A hedge is not a substitute for a fence: it can offer much more - overview of uses

This is a quick reference to diverse productive and protective (service) functions. For different social groups and situations hedges have to fulfil specific function(s). Wealthy people may plant hedges simply for optical enrichment or as a screen to retain privacy. Screening plants protect from undesirable features, such as an unpleasant view, noise, dust, insecticides, or high winds. This is important for all groups, but is not dealt with specifically. Multiple uses with the main focus on food and some herbs and medicinal plants are an example of the poor man's needs.

Hedges can provide a great variety of benefits, tangible and less tangible, e.g food, forage, wood, security, manure, erosion control, microclimate improvement. The potential uses range from planting a Henna (*Lawsonia spp.*) hedge in the compound to obtain dyes (215a), to suggestions for growing *Moringa spp.* around a field with the main purpose of obtaining a coagulant for purifying of turbid water (5a).

Multipurpose management is a general feature of hedges in developing countries. Major uses of hedges with a view biased towards the specific relevance for resource-poor land users are discussed in detail (chapter in parentheses):

- human nutrition (3.2),
- animal feed (3.3),
- timber (3.4),
- fuelwood (3.5.),
- security hedges (live fences) (3.6),
- green manure/mulch (3.7),
- water erosion control (3.8),
- microclimate modification (3.9),
- wind erosion control (3.10),
- nature conservation (3.11).

Not surprisingly various production goals cannot be distinguished precisely, e.g. soil cover, erosion protection, and amelioration are overlapping. Groups of uses can only indicate the predominant importance of specific plants and hedgerow systems. For instance, hedges as an ecosystem offer a habitat for flora and fauna (natural conservation). The stability of the ecosystem can be essential for biological pest control, reducing impact of pollutants, noise, etc.

Hedges are agro-ecosystems. A simplified example indicating important roles for small-scale farmers is depicted in Figure 5. Protection of fields against animals; wind and water erosion, supply of fodder, fuel, and other wood can be essential for small-scale farmers. The great importance of hedges for small-scale farmers becomes very obvious if we contrast his context with commercial farmers (see 4.1 and Table 1).

The role of hedges and related planting is an issue which frequently provokes controversy on its beneficial effects; it seems easy to observe the visible problems (land lost, shade, etc.). Benefits and problems are site specific and contextual. This should never be ignored.

3.2 Food and hedges

The disappearance of woody vegetation which has been a traditional source of food affects mainly the poor land users. Various ways in which hedges can contribute directly and indirectly to increasing and stabiliziing food production are discussed. Special attention is paid to vegetable hedges because their specific potential is less understood by planners.

3.2.1 Hedges and food security strategy of poor people

Deforestation has destroyed an important source of food. Wet rainforest areas (rainfall above 1800 mm) tend to be difficult for annual vegetable growing, but many trees do well. In many countries fruits, nuts, seeds, cereal substitutes, leafy vegetables, flowers, spices, etc. are harvested from hedges. Food from hedges can be very important for the poor land users because they

- can contribute significantly to the daily food requirement;
- can be harvested early and frequently;
- can be a source of valuable food in critical periods (e.g. end of dry season when no other food is available);
- can provide supplement food from edible parts of the hedge trees and wildlife;
- require little space.

Hedges play a greater role for the poor man's diet than is generally assumed. Their great potential, in particular for babies, children and pregnant women can be very important for a balanced diet. Even in a situation of sufficient forest resources, hedges are cultivated near the house; this is convenient for the daily harvest.

Hedges can contribute indirectly to improving food production by enhancing soil fertility (see 3.7), reducing soil erosion (3.8), and improving microclimate (3.9). Their overall importance to small-scale farmers for improving the food situation by supplying food and fulfilling various service functions may be tremendous in specific situations.

3.2.2 What research and development activities exist?

Today the importance of trees for human nutrition has received more appreciation among land use planners. However, there is less public awareness that food can be obtained from hedges. The great importance of hedges for the daily diet of the urban poor or rural people has been ignored and hardly documented.

Research: Sufficient information is available on nutritional value and management aspects of commonly grown trees, fruits, and nuts. This is not true of lesser known species bearing edible parts. In particular a great demand currently exists for yield data.

Development: Recently the potential of hedges for food production has been articulated by some urban planners (e.g. in urban forestry, 357). Vegetable hedges have been promoted, e.g. in West Africa (151) and in Thailand (216). The integration of fruit bearing trees into hedges as a supplementary source of food has been recommended by some development projects (e.g. 101, 151).

3.2.3 What species for food?

Species selection

Food plant candidates should:

- be culturally accepted in diet,
- have a high nutritive value,
- have no toxic or noxious components or side effects,
- be pest and disease free,
- grow fast and/or be resistant to critical periods like drought.

High-yielding fruit trees are not particularly recommended, because they are heavily pruned, thus not fulfilling the protective hedge functions. Apart from that they are often not pest and disease free. Regular pruning of annual buds may inhibit flowering and fruitbearing. In this case it may be necessary to select plants which give a dense structure without regular pruning (like natural hedges or one row of plants unpruned).

Well known species

There are many plants which can be grown in hedges for food production. For some trees and shrubs with a high potential for producing food from hedges see the following table (for more information see Table 51 and 52).

Important food trees grown in hedges for the semi-arid areas include *Anacardium occidentale, Cajanus cajan, Lanea spp., Moringa oleifera, Ziziphus mauritiania* and *Z. spina-christi.*; for the humid and semihumid regions *Bambusa spp., Brosium alicastrum, Carica papaya, Cnidiscolus chayamansa, Leucaena leucocephala, Vernonia amygdalina.* In the tropical highlands *Colletia spinoissima, Crataegus mexicana* and *Gleditsia triacanthus* are used as food.

The incorporation of fruit trees into the upper storey has been practised by local people; e.g. papayas (*Carica papaya*), bananas (*Musa spp.*) and drumsticks (*Moringa oleifera*) was observed in the savanah type climate of Thailand (215). Low care fruit trees like *Diospyros mespiliformis, Parkia biglobosa, Ziziphus mauritiania* have been found very suitable for the Sahelian region (101). Also climbing legumes like *Dolchos lablab (purpureus), Vigna aconitifolia* can be integrated into a hedge in the same agroecological zone (139).

Yield data

The production of edible parts of trees and shrubs varies widely according to resource base, varieties, and management; for yield data on some lesser known species see Table 4).

Cajanus cajan is a popular multipurpose hedge, with often a high production in pods. E.g., in Togo (approx. 1000 mm annual rainfall) a 100 m long *Cajanus cajan* hedge (316 plants) which had been cut back to 80 cm, yielded 40 kg of grains in the second year (153b).

3.2.4 Growing vegetables from hedges - a specific form of food for the resource-poor people

Nutritional value of leafy vegetables

Wild vegetables are traditionally eaten but they are no longer available in many regions. Failure to appreciate leafy vegetables is closely related to the prejudice that European types of vegetables are superior to native species. However, common kinds of tropical leaf vegetables are equivalent and sometimes superior to European varieties (compare Tables 5 and 6). Their response to basic health needs, their wide range of choices, their essential cheapness, make leafy vegetables the prerogative of a poor man's/women's luxury.

Leaves may be young and tender or old and tough. This does not influence the content of nutrients. The essential point is that tropical leaf vegetables are always a useful addition to anybody's food, especially that of babies or pregnant and lactating women.

Table 4: Yields of some trees and shrubs for food production

Species	yield/tree/kg	remarks +	source
FRUITS:			
Annona squamosa **	10-30	Fresh weight	63
Balanites aegyptiaca *	3	-	63
Brosium alicastrum **	20	for jam/floor	63
Capparis decidua *	0.5-1.5	Fresh weight, for veg.	63
Gleditsia triacanthos***	35	-	63
Moringa oleifera **	20	Fresh weight	63
Simarouba glauca**	45	dry fruits	63
Syzygium cumini *	10-15	-	63
Ziziphus mauritiana *	3-130/34	-	63
Ziziphus nummularia *	3-5	-	63
NUTS:			
Anacardium occidentale *	1-100/39	-	63
Simarouba glauca	8	-	63
VEGETABLES:			
Cnidiscolus chayamansa **	5	-	275
Moringa oleifera **	10-15	Fresh , pods/leaves, 2 harv./yr.	63
Sesbania grandiflora **	10	spinach	63
Vernonia amygdalina **	5 kg	spinach	275

+ = annual yield, if not otherwise specified
* Arid and semi arid; ** = humid tropics; *** = tropical highlands

Why vegetables from hedges can be essential for the rural poor

The great advantage of perennials over annual vegetables is that they produce over a longer period, require little or no attention for cultivation, are more drought-resistant, are often less susceptible to pests and diseases (275), and that harvest can usually start after 2 months with very high frequency, sometimes over many years.

Little care (and investment) and the living storage of nutrionally valuable food during the dry season, can make a big difference to a poor family.

Home gardens are often so small (less than 100 m2) that there is neither much space for large fruit trees, nor for low-yield vegetables like beans and tomatoes. Indeed, green leaves are the prevailing vegetables (275). To obtain a daily supply of vegetables from hedges, they are also grown near the house, even in a situation where there is sufficient land available as observed in compound farms in Nigeria.

Occurrence and species

Perennial leafy vegetables suitable for hedges for the humid zones include *Cnidiscolus chayamansa, Moringa oleifera, Nothpanax scutellaria, Sauropus androgymus, Vernonia amygdalina* (more species see Table 51). *Leptadenia hastata* is eaten in semi-arid regions. *Opuntia ficus-indica* is grown in tropial mountains as well as in semi arid areas.

In the humid tropics of Latin America *Chaya spp.* is frequently used, e.g. by the poorest population of Yucatan peninsula in Mexico (90), *Vernonia amamygdalina* is grown in compound farms in Nigeria and as hedges in West Africa (151). In the Sahel the drought-resistant liana *Leptadenia hastata* is appreciated as a nutritious leafy vegetable (366a). In Mexico *Opuntia ficus-indica* is grown as a hedge around compounds for security and as vegetable (171).

How much can a vegetable hedge produce and contribute to a balanced diet?

Vegetable hedges are able to produce young shoots continuously and give the highest yield of edible products per unit. A 10 meter long hedge may produce about 1 kg of young leaves per week for several years. Annual yield for Chaya (*Cnidiscolus chayamansa*) may range between 20-80 kg per year and for *Veronia amygdalina* between 5-20 kg per 100 meter (for more yields see Table 7).

Even a modest quantity (say 110 g or even less per day) of leafy vegetable is sufficient to balance the common diet (275). With a daily production of 150 g vegetable per 10 m hedge an adult person needs around 7 meters of a leafy vegetable hedge. An average family (equivalent to 6 adults) may require around 40 meters: in other words, a small plot of 10 sq.m. surrounded by a hedge can make a big difference to a balanced diet for a poor family.

Table 5: Nutrients in popular tropical leaves, legumes, and fruits per 100 g of dry matter, edible portions (275)

Food	protein g	calcium mg	iron mg	carotene mg	vitamin C mg
leaves[a)]	29.8	1114	18.0	38.2	552
legumes[b)]	30.0	153	8.0	0.2	7
fruits[c)]	4.6	117	3.1	4.6	299

a) amaranth, cassava, taro
b) peanuts, soybeans, mungbeans, cowpeas
c) banana, papaya, orange, mango

Table 6: Composition of tropical leaf vegetables grown in hedges per 100 g edible portion (275)

Species	dry matter g	calo-ries g	pro-tein g	fibre g	cal-cium mg	iron mg	caro-tene mg	ascorbic acid mg
Carica papaya	22.5	74	7.0	1.8	345	0.8	11.6	140
Moringa oleifera	22.4	72	7.4	1.2	295	3.6	8.9	165
Nothopanax frutic.	18.0	54	3.7	1.1	215	4.2	1.7	30
Sauropus androgynus	19.0	58	4.8	1.1	115	1.4	1.3	20
Sesbania grandifl.	24.0	77	8.7	-	50	2.7	6.2	85
Vernonia amygdalina	16.4	52	5.3	1.5	145	5.0	.	50

Table 7: Cultivation and yield of some tropical vegetable hedges

Species	Plant/10 m^2 (range)	yield/kg/m^2 average	(range)	production in yr. one
Cnidiscolus chayamansa* **	10-50	40	(20-80)	60-360
Moringa oleifera+ *	5-10	60		
Sauropus androgynus+ **	10-100	30	(10-50)	60-360
Sesbania grandiflora+ **	5-20	10		
Vernonia amygdalina+ **	25-200	15	(5-20)	60-360
Manihot esculenta**	10-20	15	(5-20)	60-270

+ woody perennial
* yield data from previous table

** (275)

3.3 Forage from hedges

Trees and shrubs are important in animal production systems. The following discussion focuses on the special role hedges can play as animal feed for small-scale farmers. Hedges can also encourage wildlife: Their specific role for bees, butterflies, and lac production will be outlined as well. In addition, see 3.11 on wildlife and role of live fences for animal production (3.6).

3.3.1 Why animal feed from hedges can be appropriate for small-scale farmers

Diverse roles of hedges for fodder

Hedges can fulfill a variety of roles in animal production. The integration of hedges in small farmers' production systems is especially justified:

- at a modest level of affordable or available inputs and management;
- when land shortage does not allow the separation of pasture from other farmland;
- when there is a need for high-quality dry-season feed for the more productive animals in a herd, and pregnant and lactating cows;
- and/or fodder for dry-season survival of animals;
- and/or sale of fodder for cash.

Sometimes hedges are also grown as a cash crop. Selling leaf meal is popular by some farmers in Thailand. Leaves of *Leucaena leucocephala* are chopped, dried for a couple of days, and then sold to mills. The back garden program of the Livestock Department in Thailand proved that using hedges is an interesting source of fodder and cash (215). In an alley-cropping proposal for the Philippines it was estimated that 40 man days of employment can be created per hectare if one of the two harvests is sold as leaf meal.

How hedges can provide animal feed

Forage can be obtained from natural-like hedges or trimmed hedges. A combination is possible as well. Fodder trees with a large crown capable of severe lopping during periods of high environmental stress can be an important emergency fodder supply. Alternatively the hedge can be grown, protected and the harvested leaves fed to livestock (cut-and-carry system).

The carrying capacity of a pasture can be significantly increased through fodder from live fences (28). Hedges can provide small fodderbanks to overcome the critical feeding periods. This may be essential for small scale farmers.

The hedge also can be grazed as a companion plant with grasses (controlled browsing system). These feed gardens can be highly productive and yet requiring only moderate management attention (example see Figure 8). Live fences and recently hedgerow intercropping are important systems of forage production from hedges. Indirectly hedges with their various protective functions can contribute to increasing animal productivity (e.g. reduces body heat). Fencing of pasture by stockproof barrier hedges or to protect young fodder trees or fodder banks can be the function of hedges as well.

3.3.2 What research and development activities exist?

Research: Research have neglected this potential in the past. This is particularly true of hedge harvesting techniques like pollarding and lopping (381); knowledge about these techniques still remains to a great extent empirical (331).

On the other side accumulated data exists on the nutritive value of woody perennials (e.g. 174, 281, 336). Information on the nutritive value alone is useless, because it is totally independent of palatability (e.g. one plant may be very rich in protein but unpalatable) (239). Reliable quantitative management data is only available for some prominent species. Today some of these research gaps are gradually being filled. Studies on alley-cropping systems by ILCA and live fence research by CATIE are showing progress. Research organisations are becoming increasingly aware that in the generating and testing phase of technologies the producer has to be actively involved (see 4.3).

Development: Today various development projects promote fodder trees and hedges; reliable information only exists on a limited number of species; therefore the implementation agencies have limited choices.

3.3.3 What species for forage?

Species selection

Trees and shrubs planted with the prime purpose of producing animal feed should have certain qualities like

- being fast growing,
- and/or hardy in the face of adverse climatic conditions,
- ideally the foliage should be palatable, nutritive, and digestible,
- fodder trees should produce a large crown above livestock reach, and be capable of severe lopping,
- hedges have to withstand hard trimming or browsing.

With regard to palatability it has to be stressed that plants believed to be completely unsuitable as forage have been recorded elsewhere as being intensively browsed and vice versa (238).

Well known species

Some important hedgeplants suitable for animal feed for the humid tropical lowlands are: *Brosium alicastrum, Gliricidia sepium, Leucaena leucocephala*; for semiarid regions: *Acacia tortilis, Atriplex spp., Medicargo arboreal, Opuntia ficus-indica*; for tropical highlands e.g. *Bauhinia purpurea, Leucaena diversifolia, Leucaena hybrid KX3, Morus spp., Opuntia ficus-indica* and for subtropical zones e.g., *Artocarpus spp.*, (for further details see Tables 51 and 52). Some lesser known species see Table 8.

3.3.4 How much animal feed from a hedge?

The contribution of hedges and fodder trees in hedges can be important (for some quantitative yield data see Table 8). The harvestable leaves, seeds and pods vary greatly accorddcing to climate, soils, species, and management.

In the humid tropics of Mexico Ramon (*Brosium alicastrum*), a perfect fodder tree, yields around 100 kg fresh weight (40 kg dry weight) per year. Mature Ramon widely spaced along livefences can even yield up to 400 kg fresh weight (216).

Pollarded *Erythrina poeppigiana* can produce more than 500 kg (dry weight) per 100 meters of hedge; (Tables 39 and 40) and Leucaena one ton. A pollarded *Gliricidia sepium* fence in Sri Lanka planted around a field was found to be a tree protein fodder bank (see Table 41).

In intensive feed gardens with moderate management attention *Gliricidia sepium* and *Leucaena leucocephala* planted in alternate rows at 4.0 m inter-row spacing, with four rows of grasses (usually *Panicum spp*) planted within the alleys (see Figure 8) produced 20 tons per ha per year of mixed grass/legume fodder under a regime of frequent cutting (18).

Table 8: List and yield data of species with leaves, pods, and seeds for fodder in kg per year

Climate/Species	leaves	pods/seeds
TEMPERATE ZONE:		
Quercus semecarpifolia*	30-40; green weight	-
Symplocos paniculata*	50-70; green weight	-
SUBTROPICAL:		
Artocarpus spp.+	20-200/77; green weight	-
A.lakoocha*	60-200; green weight	-
Bauhinia purpurea*	60-80; green weight	-
Ficus lacor*	100-150; green weight	-
F.roxburghii*	60-80; green weight	-
Morus spp.*	40-50; green weight	-
Quercus semecarpifolia*	120-200	-
HUMID LOWLANDS:		
Brosium alicastrum**	50-200/100/yr; green weight	16
Leucaena leucocephala+	50	5
Sesbania grandiflora+	10; green weight	-
SEMI ARID:		
Acacia nilotica+	-	15-70/34
Acacia senegal+	10-15; green weight	-
A.tortilis+	5-10; green weight	-
Albizia spp.+	5-29.5/17; green weight	-
A.lebbek+	9.5/yr	-
Atriplex spp+	0.7-12/3	-
A.nummularia+	1.5-1.8	-
Azadirachta indica+	10-20; green weight	-
Bauhinia spp.+	15-80/42	-
B.purpurea+	60-80; green weight	-
B.variegata+	15-20; green weight	-
Garuga pinnata*	50-100; green weight	-
Grewia optiva+	12-15; green weight	-
Populus ciliata+	20-30; green weight	-
P.cineraria+	25-30	10-15; green weight
P.juliflora+	-	10-15; green weight
P.tamarugo+	33	75
Robinia pseudoacacia+	10-15	-
Ziziphus mauritiana+	2-3; green weight	-

Note: For many of the species source does not indicate whether it refers to green or dry weight;

Source: + (63); * (281); ** (215);

A study in the tropical mountains of Costa Rica found that cutting of a *Gliricidia sepium* live fence (120 m/ha) twice a year gives a forage production of 347 kg/ha/year (dry weight), based on prevailing carrying capacity (0.7 livestock units). The hedges could increase forage availability by 10 % for cattle (28).

Table 9: Annual yield from leaves and seeds of *Brosium alicastrum* for animal feed

live fence per unit:		70 m (10 ha)	100 m (6 ha)	400 (1 ha)
number of trees:	1	11	16	66[a)]
leaves in kg[b)]	100	1100.0	1600.0	6660.0
dry seeds in kg[c)]	16	176.0	256.0	1056.0
crude protein in kg[d)]	2	22.0	32.0	132.0
livestock feed from seed	-	0.2	0.3	1.2

a) assumed intrarow spacing of 6 meter
b) in green weight (= 40 kg dry weight)
c) based on average yield of 16 kg dry weight
d) based on 12.5 % crude protein/kg

Source (216)

Seeds from mature Ramon trees grown in the humid tropics can support up to 1.2 BLU (big livestock units = 400 kg) or 1.3 TLU (tropical livestock units = 250 kg, e.g. four goats) per hectare (see Table 9).

For semi-arid areas in Yemen it was calculated that shrubs grown along a field border would produce a minimum of 3 kg (dry matter) per meter of hedgerow (or one Scandinavian Feed Unit). In other words, one meter of hedge would produce 1 day of sheep feed requirement or a bullock would need 8 meters per day. With the addition of crop residues the requirement would only be half or one third of the amount (176).

3.3.5 Harvesting: how to optimise and maximize biomass for animal feed

Feeding strategy of land manager

Hedges and hedge trees can serve as a dry season fodder bank. These banks can provide either

- high-quality dry-season feed for the more productive animals in a herd, pregnant and lactating cows, and thus increase herd productivity;
- may be grazed by all classes of stock.

If the primary consideration is dry-season survival of the animals and not to increase productivity, the first option will be chosen. There is evidence from Africa that this strategy gives a higher internal rate of return, despite lower eventual net income (260). In other situations a resource-poor land user will give special care to lactating or pregnant stock. Having identified the major strategy of the majority of the small users in an area, technical considerations become important.

Harvesting techniques and frequency

Harvesting techniques: To ensure a steady supply of leaf fodder, pollarding and lopping of certain species and chopping (for illustration see Figure 80) can be an efficient method of obtaining sustained yields; even mechanized mowing of hedges in rows is possible (252). This has been practised by commercial farmers in Thailand.

Pollarding is the cutting of the crown of a tree in order to obtain a flush of shoots, usually above the height (approximately 2 meters above ground) that browsing animals can reach. Lopping is cutting branches and tops from trees (normally lower branches).

Villagers have mastered the art of lopping and pollarding branches for fodder without killing them. This is important in Kenya (Mount Kenya) (291), Nepal (281), and Mexico where experienced people easily climb and lop tall trees reaching 20-30 m like *Brosium alicastrum*, in a short time (3-5 trees per day) (216).

Harvest frequency: The frequency of harvesting is influenced by various factors like nutritive value, taste, time of urgent need, fodder, main purpose or conflicts with agricultural crops. Many hedges can be harvested from 6 months onwards. Fodder trees are exploited much later than shrubs: semi-arid zones >10 years (176); subalpine mountains >20 years; subtropical mountains >3-5 years (281); humid tropics >4-5 years.

Combinations of hedgerows and hedge-fodder trees have advantages too, e.g. hedge shrubs and small trees for harvesting in a short period after establishing, supplemented with fodder trees established in the hedge. For some species later lopping may be important, e.g. *Brosium alicastrum* tried in hedges and pollarded after 1 year also looked promising at the beginning of the trial (284) but did not show satisfying results (216). Pods of legume trees (e.g. *Acacia spp*., *Prosopis spp*.) are produced the second and third year after lopping (176).

Optimising and maximising biomass for animal feed

Optimising: Biomass from hedges for special needs (lactating, sick animals) have been observed, e.g. in the humid tropics of Mexico (216). This is another contingency for small-scale farmers. In more arid regions the survival of the whole herd is often the most important strategy of small-scale farmers. Optimising labour or the nutritive value of fodder are other options.

Maximising: Maximising forage yield is to a great extent the same as for mulch. In both cases the non-woody component of the hedges is to be optimized (see discussion under 3.7). The main difference is that for forage, frequent cutting may be important for obtaining a harvestable animal feed. With longer intervals leaves may fall, thus not being available for the livestock. In other words, great differences can exist between harvestable feed and biomass produced for recycling (manuring).

The second difference is coppicing (pollarding) capacity. Excellent capacity may be preferred by silvopastorists as a guarantee of an adequate supply of fodder for their livestock all the year round. However, in hedgerow intercropping this may impose frequent pruning to avoid shading.

When the frequency of pollarding per year increases, the total biomass produced increases, the amount of natural leaf fall decreases. Hence, when conserving only pollarded biomass (harvestable), frequent pruning is advisable. This fits well into small scale farmers' strategies (311).

Generally, optimising leafy biomass can be achieved by higher cutting regimes and frequent harvesting intervals (55) (compare e.g. Table 39 and Figure 87). Maximising fodder has to be weighed against optimising labour or other limiting inputs (see also 6.4)

Harvesting recommendations for Leucaena

Leucaena leucocephala is one of the best researched species. The tree should be harvested after it has become well established (in optimum growing conditions: six months; in less than optimum sites: up to a year). To stimulate branching and increase yields in later harvests, it is advisable to cut back to 20-30 cm for the first harvest. Shoots start getting woody in 6 to 10 weeks and feed quality begins to decline. The following characteristics indicate it is time to harvest:

- branch height is 1 to 1.5 m,
- stem diameter at the base is 6 to 10 mm,
- stems are turning brown at the base,
- leaves are falling off at the base of the stems.

Harvest intervals vary greatly with temperature, light, and the variety used. With temperatures around 30° C and high light intensity, harvest can be every 5-7 weeks. Cool temperatures and low light can slow growth and extend - even double or triple - the harvest interval (266).

3.3.6 Hedges encourage wildlife and semi-domesticated insects

Hedges may attract wildlife. They can be an important source of food for semi-domesticated insects like bees, lac lice, and butterflies (see also 3.11).

Hedges and wildlife

Wildlife is an important source of food in many parts of the tropics. Disappearing natural vegetation can be a threat both to the nutritional situation of man and the habitat of many wild animals. Hedges can be a partial substitute. Diverse natural-like hedges with sufficient old hedge trees are essential (see 3.8).

Generally the possibility of hedges as a habitat for game is not considered at all as a topic in research and development. However when wild animals are appreciated as a source of food, the development of approaches to attract them into hedge-like vegetation and attempt a permanent (sustainable) management may be worth trying. In the North East of Thailand, people are keen to eat wild lizards. Hence an NGO considered the possibility of trying wildlife management in hedges. The project was suggested for schools.

In temperate zones recorded empirical and scientific knowledge exists on how to attract several useful species into hedges. More research efforts in developing countries are warranted. Probably many local people have empirical knowledge.

Hedges can be an excellent bee pasture

Great advantages of beekeeping include the fact that it never competes with other uses of woody plants. It can contribute very quickly to cash income and food supply. The production of honey is necessary for their propagation by means of pollination by the bees for various crops (fruit trees, *(Curcubitacea* (now better known as *Poaceae*) *Leguminoses*) (304).

For intensive bee forage the most promising trees and shrubs for honey and wax production for the humid tropics include *Calliandra calothyrsus, Cocoloba unifera Gliricidia sepium, Leucaena leucocephala*; for the arid and semi arid regions include *Acacia spp., Eucalyptus spp, Prosopis spp.* and some *Poaceae. Acacia decurrens, Gleditsia triacanthos, Grevillea robusta* and *Melia azaderach, Morus alba* attracts bees in tropical highlands (for others see Table 51 and Table 52).

A year-round supply of flowers can be very essential for poor land users who start apiculture. *Calliandra calothyrsus* is a fashionable species in forestry projects which promote beekeeping in Asia. In the North-East of Thailand with a prolonged dry season, poor people who tried beekeeping failed because they could not afford to buy syrup to overcome the food shortage.

The implication is that hedges have to be designed to provide a year-round supply of feed for animals. A natural hedge with a sound combination of plants including flowers in the undergrowth will be most appropriate. Space limitations have to be considered in design.

Hedges can be an attractive host for shellac producing insects

Shellac is made from the resinous exudation secreted by the "lac insects" (*Laccifer spp., Cocidae spp.* and some others) in the form of incrustations on the twigs. To secure a regular and high yield the woody perennials have to be cut back after a productive phase (304). Insects produce on the twigs of certain plants like *Acacia spp., Albizia spp., Butea monosperma, Cajanus cajan, Croton spp., Ficus spp., Flemingia macrophylla, Sapinadacea, Scheria olesa,* Cochenille-lice on *Opuntia spp.* (304).

Lac production on hedges can be an attractive incentive for soil conservation. In Thailand lac lice (*Laciser lacca*) raised on pigeon peas (*Cajanus cajan*) planted on contour bunds for erosion control has been promoted by a project. Loss of cropping through conservation can be more than compensated by the selling of stick lac and pigeon peas (348)

Hedges can be an appropriate component in ecologically sound butterfly farming

The international demand for tropical butterflies is high. Butterfly farming may become a high value/low volume species crop. This can be very attractive for remote rural areas and resource-poor people because the capital cost involved is minimal. In Papua New Guinea villagers are both earning money and practising sound wildlife conservation (253). The latter is not the case when focusing only on common species and divorcing the farm from the natural habitat (battery production, etc.) (73). The key to success rests on choosing commercially attractive species and possessing botanical know-how on plant species that various butterfly species use during their life cycle (253).Easy and quick access to market seems important as well.

Contribution of hedges: Many butterflies only visit hedges occasionally. But they can nevertheless form an important component in their life cycle (93). There is some evidence that in ecologically sound butterfly farming hedges are an important component. In the humid tropics hedges consisting of *Hibiscus spp., Bougainvillea spp., Ixora pinsettia* have been used in butterfly farming in Papua New-Guinea.

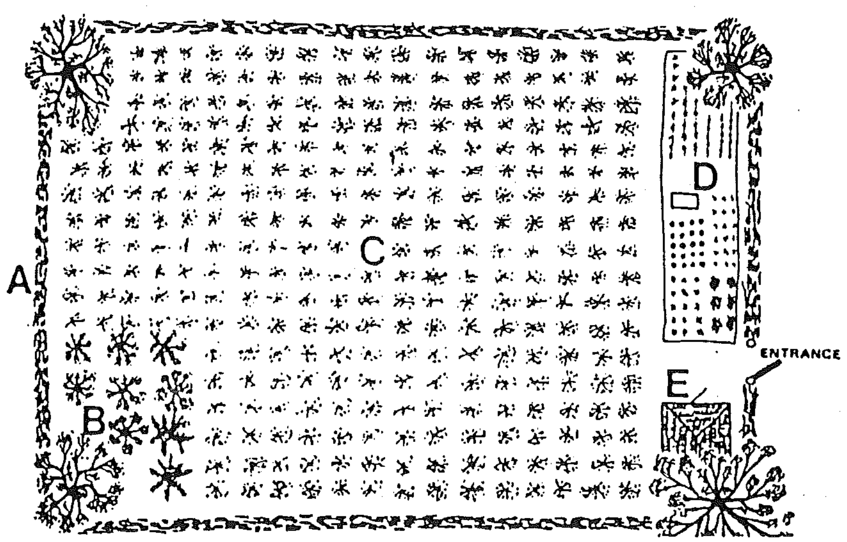
It proved essential to surround the site (0.2 ha) with a thick hedge of other nectar-bearing plants, whose flowers attract adult butterflies and encourage them to remain in the area. The hedges also keep out pigs and other livestock that may damage the leafy plants inside the farm (for illustration see Figure 7). Hedgerow patterns which combine sound wildlife management with other uses are very important for resource-poor land users.

3.3.7 Problems that may occur when growing hedges for fodder

Where there is no traditional use of fodder trees in farming systems this might be a constraint. Cut-and-carry systems may be perceived as being too labour-intensive in a region in which the animals seek their own food or there are no local mechanisms to prevent over-exploitation of the common natural resources.

Taking away leaves without adequate return of nutrients to the soil may lead to the multipurpose exploitation syndrome.

Establishment of hedges, particularly as fodder banks, may not be carried out if the perceived costs of protection in the initial stage are likely to be higher than the expected benefits. The biggest obstacle in alley grazing can be the debarking of the legume tree by grazing animals, especially goats (18).



A Hedge of *Hibiscus spp., Ixora spp.*, and poinsettia
B Fruit trees (such as lemon)
C *Aristolochia spp.* vine grown on the branches of trees
D Nursery area
E Hut for tools

Figure 7: Stylized diagram of a butterfly farm (253)

Butterfly farming is technically "ranching" (the breeding stock are quite free in the vegetation). Butterfly farmers build up their "livestock" by clearing small areas of ground and planting leafy food plants for larvae to gether with the nectar producting flowering plants that adult butterflies feed on. The key to farming butterflies is to establish a garden of plants that various species need for their liefe cycle. The ideal farm is abuot 0.2 ha surrounded by a thick hedge to keep out pigs and to provide nectar.

slightly modified from 253

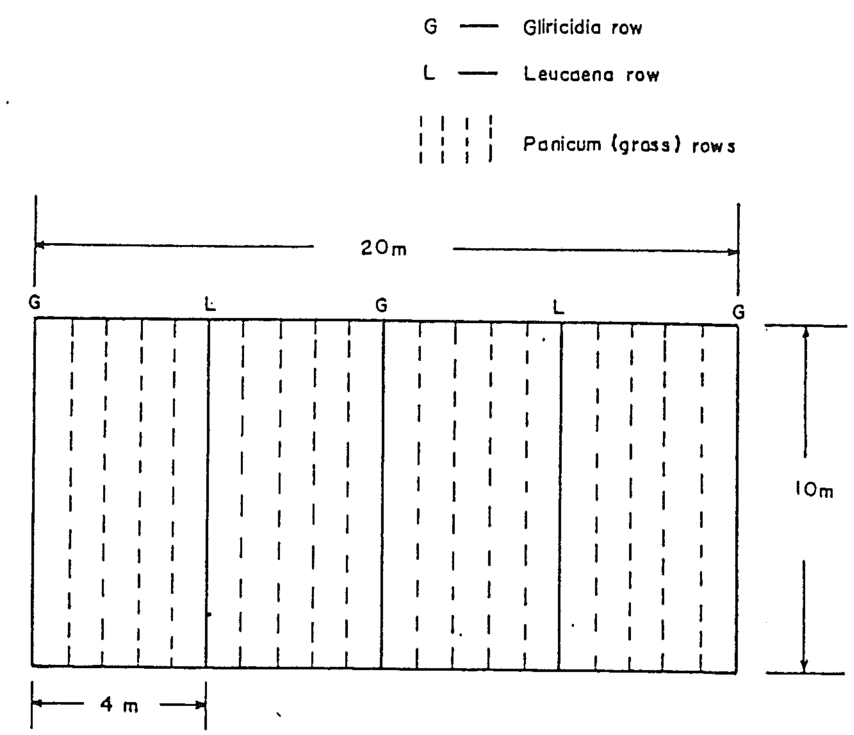


Figure 8:Intensive feed garden with a Gliricidia hedge component (18)

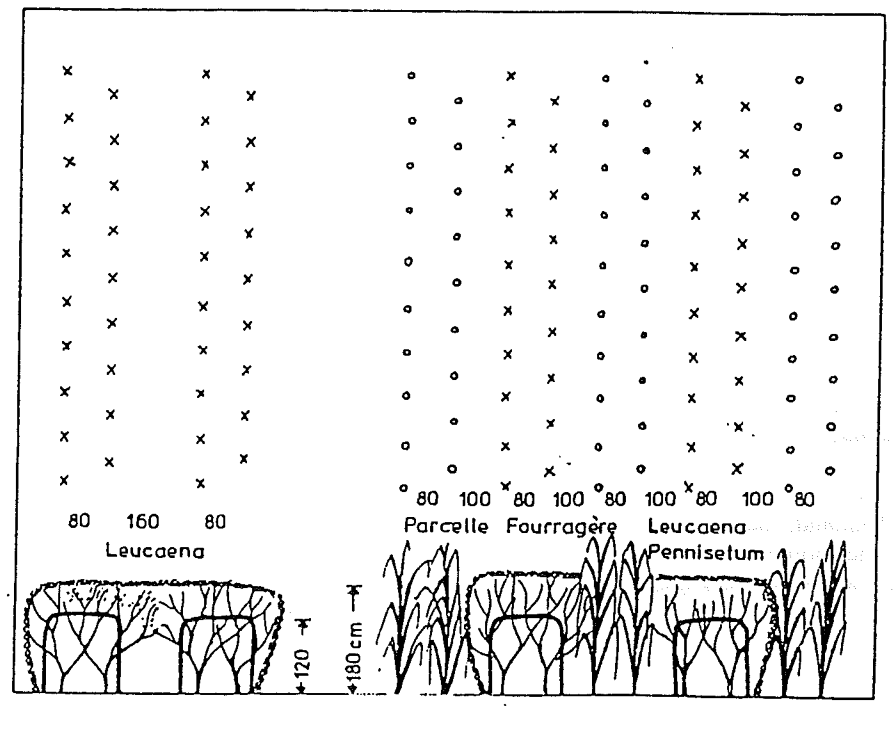


Figure 9: Design of a hedge based forage production system in Rwanda (298)

3.4 Timber from hedges

Natural woodlands have been a very important source of timber. When these resources dry up, other sources have to be considered. Small-scale farmers and poor people are most affected when wood resources are depleted.

The quality of life of resource-poor land users often depends on wood. Natural woodlands have been a very important source of timber. When these resources dry up, other sources have to be considered. Small-scale farmers and poor people are most affected when wood resources are depleted. How hedge trees fit into this strategy will be demonstrated. Since commercial timber has been the main concern of tropical forestry only specific aspects of hedgerow timber will be discussed, like how to obtain high quality commercial timber from hedge trees.

3.4.1 Hedge trees: An excellent asset for meeting contingency and subsistence needs

Woody plants grown in hedges may be a very important source of wood for the poor. Their supply is essential in a situation where all natural forest has gone, and village woodlots and other woody vegetation are not accessible to the poor.

Hedgerow timber trees, if properly managed, have the advantages that

- they can grow quicker than plantation trees, due to the wide spacing and access to light and nutrients;
- they can attain the growth required for veneer timber;
- also for various uses short logs, poles and posts can be obtained from hedges;
- timber from hedge trees can satisfy subsistence needs or be used as asset for meeting contingency needs (security savings).

The specific advantages of growing hedgerow trees for timber have to be evaluated against the pros and cons of hedgerow trees in hedges (see Table 2). In all cases the undergrowth of a hedge tree may suffer. Hence stockproof hedges and timber production should not be considered in most cases. High-quality timber can fetch a price up to 20 times higher than low-quality timber (189). Roadside hedges are good sites, as the timber is easy to extract and shading of crops is a minor problem (44).

However straight trees may not be the prime concern of local people, e.g. trees which split into planks using a wedge are required for a type of housing and technology used in the Congo. "Y"-shaped posts are always used for traditonal housing and granary supports in many parts of Africa (173).

Contingencies: Some hedgerow trees integrated into a hedge can provide an excellent means of meeting contingencies: savings and security. Timber can be easily stored, gathered, and sold when there is a need and when no other source is available.

Obtaining a high-quality hedgerow timber involves pruning. This is welcome for fuel by small-scale farmers. The conventional silvicultural strategy for producing branchless trees is by close planting. A resource-rich farmer in Mexico decided to plant a village woodlot, a resource-poor one to integrate a few precious timber trees into his hedge. This demonstrates that what can be a village woodlot for richer people might be a few hedgerow trees for poorer people.

In the North East of Thailand, *Eucalyptus camaldulensis* has been grown around fields or integrated into hedges by settlers. Some of the farmers saw the trees as a contingency asset (security, saving). Even money lenders considered these trees suitable for mortgages.

Figure 10: Differences between a high class hedgerow timber and a timber of poor quality (189)

Bole with high class timber: The aim is to minimize the number and size of knots in the tree trunk that will become a log. Live branches make thick knots and dead branches make loose knots, both of which determine the quality and hence the price of the log.

Hedge tree with many branches: Depending on the specific market a tree with many branches yields a low price, because it cannot be used for sawn timber and veneer.

3.4.2 What research and development activities exist?

Research: Forestry has focussed on commercial timber obtained from plantations or natural forests. Despite the importance of round wood (poles/posts) surprisingly little has been written about the management of trees for roundwood production or the use of roundwood timbers (38). When the international community finally became aware of non-industrial needs like fuelwood, timber needs had been neglected.

CATIE included some studies on traditional systems for producing poles from living fences (224). The majority of research and development organisations have not gone into the potential of the role hedges can play in increasing timber supply. Even where farmers indicated (e.g. in Nepal) that border tree planting would be the most appropriate place for farm forestry (264) no departure from plantation forestry was made in community forestry.

Development: There is hardly any systematic promotion in development projects which attempt to support the farmers in the technique of obtaining valuable timber from hedge trees and selling it for a fair price.

3.4.3 What species for timber?

Species selection

The qualities of species for suitability as timber can be divided into wood and silvicultural characteristics. Species used for timber should have following features:

- height,
- density,
- dimensional stability,
- natural durability,
- resistance to termites and other wood borers.

Poles should

- be durable, light,
- be capable of taking high cross-load (high strength to diameter ratios for a given length is vital),
- have minimal spirality to avoid opening up when in use,
- be resistant to wood borers (38).

Well known species

Important timber species include for the humid tropics *Brosium alicastrum, Khaya senegalensis, Dendrocalamus strictus* and other bamboos are important for poles. In the arid and semi arid regions *Acacia nilotica, Acacia senegal, Azadirachta indica, Eucalyptus camaldulensis, Parkia biglobosa, Prosopis africana,* and *Pterocarpus spp.* provides valuable timber (more species see Tables 51 and 52).

Old trees from *Gliricidia sepium* hedges are used in Costa Rica for construction timber, railway sleepers (27)

Yield data

Production data are very rare. Generally it can be assumed that the growth rate of free-standing trees can be three times higher than in plantations (8). However, very closely set hedgetrees may suffer,due to intra-species competition for biological resources.

3.4.4 How to produce high-quality hedgerow timber

If it is intended to grow commercial timber trees in hedges, the site is of importance (access and ease of extraction). Hedges can be grown from nursery stock or spontaneously in the hedge. The easiest way to establish hedgerow trees is to keep an eye out for promising straight saplings. Cut off the lower branches and decaying shoots to encourage a good crown and fewer knots in the trunk. Thereafter leave the developing tree alone when trimming the hedge. It is very appropriate for small-scale farmers to leave a few vigorous trees out of the trimming operation. Poles or even high quality timber can be produced. Although it is easy to wait for the right seedling to establish themselves in the hedgerow, if the farmer wants to supplement or speed up the natural process trees can be planted.

Top-quality timber must be of minimum length of unblemished stems, i.e. without wounds, faults, branches or knots (189). Proper management includes pruning and protection (189)(see Figure 10).

Pruning of a hedge tree depends upon age and maturity . To obtain a straight bole (branchless trunk) silvicultural treatment includes:

- coppicing,
- high pruning,
- thinning.

The suppression of the leading growth will be the decisive factor. By training the shrub may grow into a small standard tree (more deatils see 6.3.4).

Thinning: The removal of plants may be important to reduce the population and accelerate incremental diameter growth. There should be no hesitation in deciding to destroy poor and unsuitable species. Replacement may be the better policy (47, 189).

3.4.5 Problems that may occur

The slow growth of timber in more arid regions may impede the production of commercial timber from hedges. The time frame may be too long for resource poor people. A problem with hedgewood timber could be that the hedges become weak under the umbrella. Cattle standing under trees may pose problems like making the soil too compact. On the other hand hedge trees may be well protected in the hedge (44, 377a).

Insecure tenure and markets may be a more serious problem for tenants and spontaneous settlers. Share cropping can impede growing hedge trees, if the contract between landlord and tenant is shorter than the time needed to harvest timber. Insufficient understanding of silviculture of hedge trees and multipurpose management which does not jeopardize timber production may exist among "Non-Arboriculturists" and local people.

The timber may be valueless in terms of commercial wood if it has fence wire, staples or nails in it or is difficult to fell, transport and sell. Hedge trees may ruin saw teeth due to embedded nails, staples, and bits of barbed wire. Promotion of commercial timber production from hedges can conflict with subsistence needs of the poor, e.g. need for Y-shaped poles and other non-industrial wood.

3.5 Fuel from hedges

It is not an oil crisis but a fuelwood energy crisis that affects the rural poor. This chapter demonstrates how hedges can improve the energy supply of the rural poor. A quantitative assessment of the supply from hedge to household energy requirement is included. Rapidly dwindling natural forests have a dramatic impact on fuel supply for many regions, especially for those groups who cannot afford other forms of energy. Every day more people will be using fuelwood faster than it is being replenished if present trends continue. In this context all possible ways of improving the energy situation have to be considered .

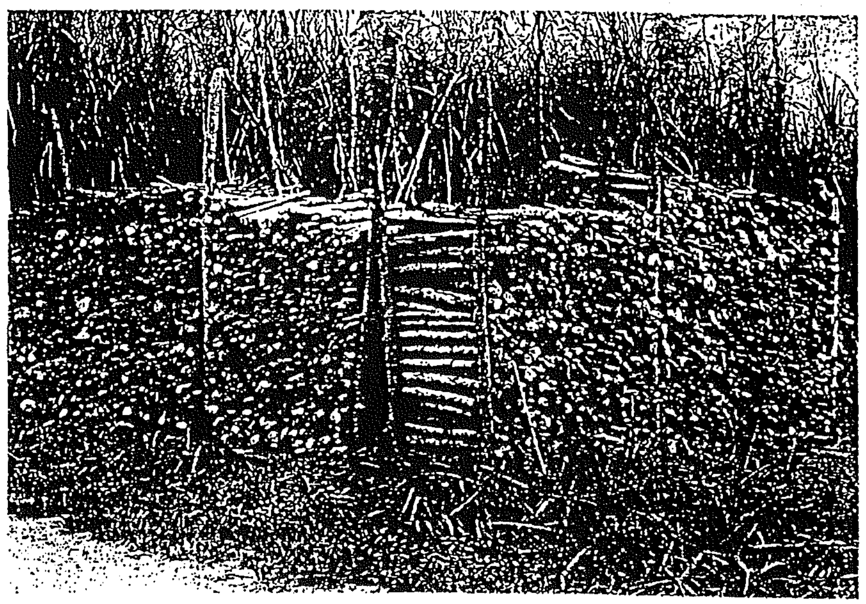


Figure 11: *Leucaena leucocephala* hedgerow prunings as source of firewood (202)

3.5.1 How hedges can improve the energy situation

For improving the energy supply hedges can contribute to:

- increasing production,
- conserving energy,
- substituting for fuelwood.

Production: Hedges can contribute directly to increasing the supply of fuelwood, sometimes on an unexpectedly large scale; indirectly by conserving energy and in some cases by growing alternative energy crops in and as hedges.

Conservation: Energy conservation may be a very important way of saving wood in mountain regions. Barrier plants can reduce the energy cost of buildings (341). Evergreen shrubs and trees forming a continuous row next to a building create a "dead" air space between building and wind. This air space acts as insulation which can reduce heating and cooling costs (76).

Substitution: Potential energy crops including oil-producing plants (*Cocos nucifera, Elaisis guineensis, Ricinus communis*, etc.) and hydrocarbon-producing plants like *Euphorbia tirucalli* (7) can be planted as barrier plants.There have been trials to replace diesel fuel with oil derived from the seeds of *Jatropha curcas.*

Another possibility suggested was to create windbreak systems by leaving a gap within a strip, lined with exceptionally windfirm trees and facing in the direction of the prevailing wind. This would have the effect of funneling and therefore greatly intensifying the strength of the wind; and the leeward end would be a suitable site for an electricity generating or pumping windmill (92).

Substitutions may be promising for the future. However, despite the increased difficulty and cost of obtaining wood for fuel, alternatives are too costly or impractable for many people. For at least the next decade the only option for the poor will be to grow more firewood trees and shrubs (98). The importance of hedges for the rural poor will increase.

3.5.2 What research and development activities exist?

Research: Although the importance of hedges for fuel supply has been realized, insufficient research has been done on this topic. Even some interesting vernacular systems still remain to be discovered by research.

Today much information exists on burning and physical properties and important fuelwood species. The state of knowledge about the quantitative data of firewood produced in traditional systems is less satisfying (227), particularly on hedges. Important source books for fuelcrops (e.g. 226, 254a) indicate hedge uses for some species; but they do not provide quantitative data. Most production data come from a few species, particularly from hedgerow intercropping and shelterbelt projects. In this context special mention has to be made of IITA .

CATIE, particularly the attached 'Alternative energy' project has done pioneer work on the study of socio-economic and technical aspects of fuel potential from living fences in Central America. The FAO/RAPA regional project has shown great interest in hedges (summary see e.g. 217). Information exists on trials for evaluating biomass yield from hedges including seeds for oil from *Jatropha curcas* (164).

Development: In times of firewood energy crisis the value of fuelwood outside the forests, including hedges, becomes appreciated (142). Hedge growing is recommended in various projects, e.g. Rwanda (298), Sahel (101), Thailand (215), Sri Lanka (67), and is mentioned in forest development plans like the one in Mexico (134). Earlier recognition of the high potential of fuel from hedges is rare (for a notable exception in the case of India see 373).

3.5.3 What species for fuel?

Species selection

All trees and shrubs may be used as fuel if sufficiently dry. When the moisture content is the same the energy given off from a piece of wood is more or less the same on a weight basis irrespective of species (276). There are species that burn easily and quickly while others burn slowly and with a small flame.

Species grown primarily for fuelwood in hedges should

- grow fast,
- possess excellent coppicing and/or pollarding capacity,
- have high calorific value,
- burn without smoke or sparks,
- possibly be suitable for charcoal making,
- be locally accepted.

Various species are suitable for charcoal (generally the dense ones). Even in areas with severe fuel shortage people may be amazingly selective in fuelwood choice (238).

The case of *Cajanus cajan* shows that productivity in terms of biomass production makes up for comparatively poor fuel characteristics (low specific gravity and high moisture content) (268).

Well known species

Important species with high fuelwood potential for the humid tropical lowlands are: *Calliandra calothyrsus, Erythrina spp., Gliricidia sepium, Hibiscus tiliaceus, Leucaena leucocephala*; for semi-arid regions: *Acacia nilotica, Azadirachta indica, Balanites aegyptiaca, Cassia siamea, Diospyrus mespiliformis, Prosopis juliflora*; and for tropical highlands: *Alnus jorullensis, Buddleia spp., Cassia spp., Colletia spinosissima, Schinus molle, Tecoma sambucifolia* (for others see Tables 51 and 52, and for Andean region see Table 57).

3.5.4 How much fuel from a hedge?

There are great variations between and within species according to agroecological zones, variety, and management applied, e.g. pruning frequency and height (Table 10 summarises the fuelwood potential of well-known species grown in hedges or windbreaks).

Fuelwood production from a 100-meter hedge can vary considerably; between 50 and 1800 kg per year. A yield of 100 kg can be expected in semi-arid regions if the prime purpose is fuel; in more arid regions it can be very low. In more humid zones the production of much higher biomass per year is possible; with rotations of 3-4 years 1000 kg and more are no exception. Even at 3500 m altitude 1700 kg annual yield has been recorded in a four year rotation.

In alley cropping 15 tons have been obtained from *Gliricidia sepium, Leucaena leucocephala* hedgerows, when allowed to grow uninhibited for one year, can easily reach a height of over 7.5 m and can produce more than 88 tons of wood per ha (112). Generally alley cropping aims to produce biomass for mulch/green manure, and as a by-product fuel. Hence it is only in a situation in which fuelwood is a primary management goal that the land manager will attempt to achieve higher wood production in alley cropping.

Classical windbreaks with a long rotation (10-20 years) in more arid regions, even when planted along irrigation channels, sometimes do not produce more fuel than can be obtained from hedges in a short rotation. The wind protection afforded by many hedges can be even more efficient than classical windbreaks. A biomass inventory in a district in Kenya calculated that the total air-dry weight of hedges per hectare was up to 16.85 t (41).

Table 10: Production of firewood from hedgerow systems

Species	Land use system	Region/ Zone/Country	Fuelwood/ Unit/yr	Fuelw. 100 m dw**	Source
Highlands					
Calliandra callothyrsus	tree intrarow spacing 25 cm, cutting height 165 cm	Rwanda highlands	5,830 kg/ha	126 kg	263
Calliandra callothyrsus	new hedgerow, intrarow spacing 25cm, pruning 5 and 10 month cutting height 25 cm	Costa Rica	1,229 kg/km	123 kg	21
Cassia spp.	4 years old Cassia, field-border plant., spac.1.5 m betw.trees	Peru(Sierra) 3500 m	105 kg/ tree/yr	1,750 kg	34
Erythrina poeppigiana	shade tree in coffee plant.,1 pollarding/yr	Costa Rica	54.3/ tree/yr	1,810 kg[a)]	311
Leucaena leucocephala	dense hedge,intrarow spac. 25cm, cutting height 45 cm	Rwanda highlands	1,770 kg/ha	70 kg	263
Humid tropics					
Cassia siamea	Tree interrow spacing 4 m, cut after 2 years, degraded Alfisol	Nigeria	14,850 kg/ha dw	594 kg	403
Combretum quadrangular	on rice field dikes,5 yrs rotation spac.1.5 m betw.trees - first cutting: - sec. harv.onward:	S-E Asia	0.6-1m³/400m/5yrs 1.2-2m³/400m/5yrs	<29 kg* <71 kg*	30
Flemingia macrophylla	interrow spac. 4 m, prun. after 2 yrs, degraded Alfisol	Nigeria	3,400 kg dw/ha	136 kg	403
Gliricidia sepium	interrow spac.4 m,prun. after 2 yrs,degraded Alfisol	Nigeria	7,250 kg dw/ha	290 kg	403
Gliricidia sepium	intercropping spac. 2 m 5 prunings/yr	Nigeria	2,640 kg/ha/yr	53 kg	202
Gliricidia sepium	interrow spac.4 m, 5 prunings/yr	Nigeria	1,470 kg/ha/yr	59 kg	202
Gliricidia sepium	2 yrs old livefence post (616/km) around plantation	Costa Rica	18.8/kg/ tree	1,158 kg	224
Leucaena leucocephala	interrow spac.1,5 m interrow spac.4,5 m	lowland humid tropics	1,610 kg/ha 117 kg/ha	350 kg	364
Leucaena leucocephala	interrow spacing 2 m 5 prunings/yr	Nigeria	6,980 kg/ha	139.6 kg	202
Leucaena leucocephala	interrow spacing 4 m 5 prunings/yr	Nigeria	5,780 kg/ha	231.2 kg	107
Semi arid regions					
various shrubs	used for fodder every 2 yr, and harvest branches every 4yr	semi-arid	4 kg/m³/kg	100 kg	176

*1.4 m³ = 1000 kg average (244)

**dw = dry weight

How much does a hedge contribute to energy requirement?

Fuelwood consumption varies enormously between, as well as within countries. In colder mountain regions, fuel consumption is generally higher because heating is important as well. Where wood is scarce people may use only 500 kg per head (238). As a pragmatic rule of thumb 1000 kg/adult person can be assumed, in areas with scarcity less than 500 kg.

To be self-sufficient in fuel one adult person may need less than 500 meters of hedges per year. The range is in the order of 30-500 m. A 400 m hedgerow (surrounding one hectare) has been proved to be sufficient for a family (equivalent to seven adult members) in the Sierra of Peru. The supply of fuel from alley cropping can meet the energy requirement of 7 to 14 adults. However alley cropping is seldom practised to maximize fuel.

Table 11: Fuelwood supply from hedges per household and per capita[a)]

	System	Country/ Region	Family/ Adults	1 Adult	Fuel/Adults in alley crop./ha[b)]
MOUNTAIN:					
Cassia spp.	Live fence	Peru	400 m	60 m	-
Calliandra callothyr.	Live fence	Rwanda	5,560 m	790 m	-
LOWLAND HUMID:					
Calliandra callothyrsus	Live fence	Costa Rica	5,690 m	810 m	-
Cassia siamea	Alley cropping	Nigeria	1,180 m	170 m	14.9 Adult
Combretum quadrangulare	field border hedge	S-E Asia	9,860 m	1,410 m	-
Erythrina poep.	Live fence	Costa Rica	390 m	60 m	-
Gliricidia sepium	Alley cropping	Nigeria	2,410 m	350 m	7.2 Adult
Gliricidia sepium	Live fence	Costa Rica	1,130 m	160 m	-
Leucaena leucoceph.	Alley cropping	Sri Lanka	4,600 m	660 m	7.6 Adult
SEMI-ARID:					
spec.from fodder hedge	Live fence	-	7,000 m	1,000 m	-

a) production data from previous table

b) based on an annual consumption of 1000 kg/adult person which may be higher in mountain regions and lower in other areas; in case of scarcity annual consumption may drop to less than 500 kg

In Rwanda it was found that around 70 trees (depending on species mix and the frequency of harvesting) will supply all the wood needed by a family of 6. Harvesting is done by lopping branches (an average year provides about 20 kg of dry fuelwood on a sustained yield) (381).

In Kitta/Malawi a study on *Jatropha curcas* estimated that each village has around 5 km of *Jatropha curcas* hedges or totally 465 km. It was calculated that 4 plants per meter run of hedge produce 1 kg of seeds. Hence the potential energy is 1860 tons, which is equivalent to 620,000 liter of *Jatropha* oil (166a). Results of a study in Cap Verde showed that self-sufficiency in energy for three households is possible by cultivating one hectare of physical nuts (600 trees). This provides sufficient oil for a small engine (208). *Jatropha curcas* planted at a distance of 4 meters around two hectares would be sufficient may be sufficient for a family to produce enough seeds to replace diesel fuel (164a).

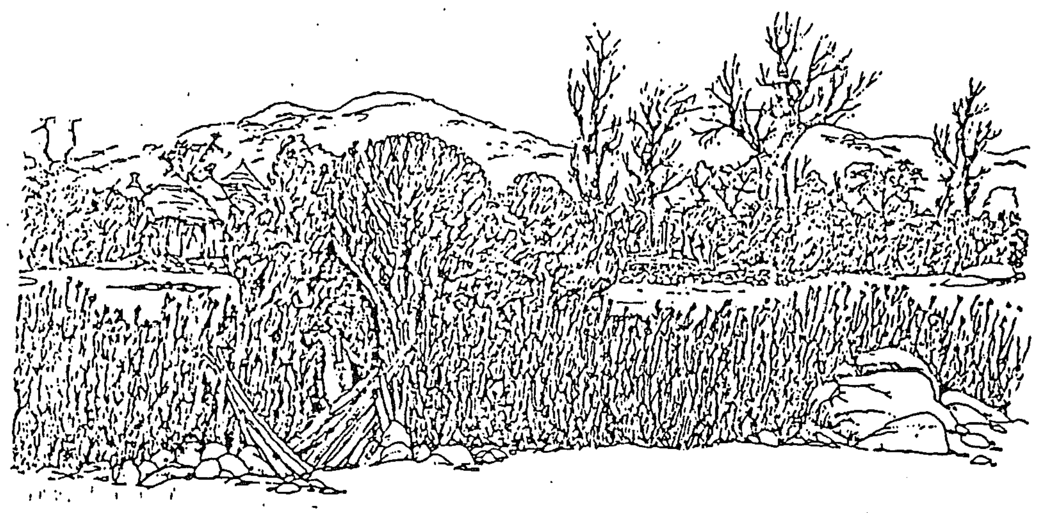
3.5.5 Problems that may occur when growing hedges for fuel

It is common that firewood production may not be perceived as a top priority due to the availability of natural forests (even when over-exploited). The locally-preferred fuel species may not be the most suitable for hedgerow growing in a particular area. Fuelwood production for subsistence may conflict with other needs, e.g. when the price of poles is high, farmers may give up the traditional right of the poor to harvest their hedges for fuel.

3.6 Security hedges (live fences)

There is a need for fencing in various land uses. This can pose extreme problems for poor people. The following discussion gives an overview of live fences, including main categories, species, examples of occurrences, and design guidelines.

front view



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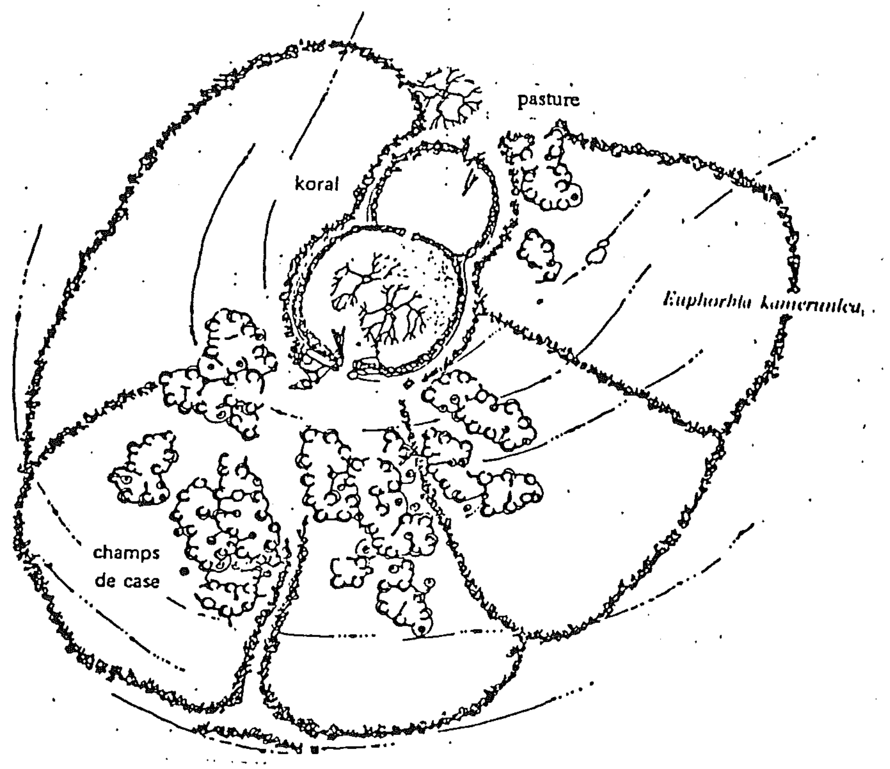


Figure 12: Euphorbia defence hedge in Chad and North Cameroon

3.6.1 Poor people need low-cost fencing

Where there is plenty of timber and sticks available, a palisade can be constructed from these materials. In wood-scarce areas like the Sahel very often only thorny brushwood is available. The amount of wood needed for dead fences can be quite high. In Senegal a standard compound protected by 100 m of fence would require 350 kg brushwood every five years. If fields are included, well over 700 kg (1 m^3) per year of replacement brushwood is required for fencing (238). When these traditional sources cease there is a need for low-cost fencing for the poor land users, e.g. around pasture, fields and woodlots.

In South West Cameroon, hedges are used to keep rodents out of farmers' fields (348a). Free roaming livestock can inhibit farming, e.g. farmers in Timur/Indonesia spend up to two-thirds of their total work input in arable cropping on the construction and maintenance of traditional wooden fences (286). In gardening, particularly nutrition-oriented projects, fencing has been identified as a principal problem. Chicken wire and/or barbed wire are too expensive for the rural poor (279). Modern pasture management essentially involves the division of land into defined grazing areas. Fencing is most desirable for this purpose, but it is expensive, thus posing a major constraint to pasture development (81).

In semi-arid Africa, enclosure of rangelands and registration of exclusive rights to grazing by individuals or groups has increased, because of pressure at two levels: official planning (modern use of rangeland, market-oriented production), and initiatives by pastoralists as a response to the perception that good land is becoming scarce and there is a need to lay claim to a demarcated area in order to protect grazing rights.

In the case of agro-pastoralists in Somalia there are two different reasons for enclosing land: to reserve arable land for future use, and to control grazing land. Farm and pasture land close to settlements and water points close to settlements do not voluntarily give up their farms; often they are forced out by a lack of affordable fencing material (26).

A big item in budgetting costs of public plantings is the fencing required to protect saplings from livestock (9). This is particularly true of strip/band planting (143a). A forestry plantation with barbed wire attached to dead posts accounts for up to 30 %, sometimes even half of the total plantation cost in Nepal (122).

Commercial farmers and projects can afford to invest in capital-intensive electric fencing or dead posts with barbed wire attached.

3.6.2 Relative advantages of live fences for resource-poor people

Dead fences may be very expensive and do not provide additional benefits. Small scale farmers and poor citizens need a low-cost fencing with a variety of outputs. Fences created with trees and shrubs are common in developing countries (366). Live fences are not a substitute for dead fences, they are more, because they can provide diverse outputs for the resource-poor land user.

Live fences are plants with the function of demarcating and/or forming a barrier. They can act as "exclosure" or enclosure or both. The role of woody perennials is to provide fence posts for supporting wire or to form a line, spaced closely enough to form a barrier. Security hedges, barrier plants, and quickset are synonyms for live fences. "Quick" or Quickset at first meant any living hedge, not necessarily of thorn as understood today (93). However, few are totally effective as a security hedge.

With regard to the degree and style of fencing three main types of living fences can be distinguished:

- more or less permeable: general barrier fence (marking boundary, garden fence);
- impermeable for big livestock: living fence post supporting wire;
- impermeable for people and animals: stock-proof fence without barbed wire.

The most important function of live fences is to delineate areas designated for houses, agriculture, forestry and animal husbandry. Security hedges serve primarily to prevent the passage of animals and people; to enclose or exclude either animals or crops, or both. Apart from the role of fencing they can fulfil various protective and productive functions. Live fences often mark land ownership (or rental). Relative advantages of live fences are particularly important in grazing-browsing systems under arid and semi-arid conditions, where costs for fencing per head of livestock go up as carrying capacity decreases, or in humid regions, where each post has to be replaced often (327b).

Barbed wire fencing can make browse plantations for small-scale farmers economically unattractive (200). Some Fulani in Nigeria were faced with high costs for barbed wire fences and the destruction of the dead posts by termites. In this situation some farmers rediscovered the value of traditional inexpensive living fencing, mainly made of Yucca spp. (377). Barbed wire fences are generally four times as expensive than living fences; in Nepal as much as 25 times (compare Table 29). For a summary of the relative advantages of living fence posts and dead posts compare Table 12).

The need for fencing can be reduced by land use zoning. The role of living fences in local land use zoning has been demonstrated by the Bamileke in Cameroon (see case study Appendix 1). Faced with high fencing costs for forestry plantations, the removal of the barbed-wire fence some years after establishment is often recommended (e.g. 122). "Social fencing" combined with economically attractive low-cost living fences is more appropriate for poor land users.

3.6.3 What research and development activities exist?

Increasingly the great importance of living fences as a low cost technology has been stressed by various development projects; yet they are not a research priority (recent example see 366).

Research: Some investigations on living fences have been conducted. Most results are based on trial and error by farmers. In the last century Esponda tested various species with regard to their stockproof quality for big livestock in tropical montane Mexico. *Cordia dentata* proved to be the best (109). In the New Hebrides experimentations were done with local species to avoid costly barbed-wire fencing (58).

For years, CATIE in Costa Rica has paid much attention to biological and socio-economic issues of living fence posts supporting wire (50). This reflects the special situation in Central America. The results are not applicable to the very poor ranchers without access to development resources. This limitation is seen by CATIE today (51).

ILCA has developed a sheep-proof Leucaena fence (see Figures 17 and 18). ICRAF does not put special emphasis on live fences. Activities are limited to a few demonstrations of living fences on ICRAF's field station in Kenya (255) and references in databanks and libraries.

Some older and a few newer country examples are available for Cuba (77), Costa Rica (318), Mexico (316,), Haiti (244); South Africa (165), and southern Africa (166).

Today the need for cheap fencing is seen by various projects (372). Some of them are experimenting with living fences without waiting to obtain support from research organisations. Live fences are developed and/or promoted in various projects, e.g. in Ghana a stockproof-cum-firebreak fence (389), and in Nepal a *Ipomea fistula* fence to protect fodder trees (321). In Central Java, Perhutani (the State Forest Corporation of Indonesia) introduced living multipurpose hedges into teak plantations (242) (layout see Figure 54). However, most of the projects promote a few well-known species like *Gliricidia sepium* and *Leucaena leucocephala*.

Table 12: Comparison of living fence posts with dead posts

Factor	Live fence	Wooden (dead) fence
Choice of species	Depends on ecological conditions	Many possibilities: depends on availability
Cost	Relatively low or free	Relatively high
Handling of post before placing	Needs careful preparation, transport and storage	No special care required
Placing in soil	Needs care, adequate soils	Soil not limiting
Placing of barbed wire	Special techniques in some species	Some skills required
Initial maintenance	Necessary, requires protection against some animals	None, in some cases needs fire protection
Survival	Losses possible	100 per cent
When to place wire	Usually when well-anchored	Immediately
Increase of post density along fence	Easy and cheap	Easy but expensive
Durability	Usually very long	Variable, limited according to treatment and species
Organic matter production	Varies with species	None
Nitrogen-fixation	Possible in some species	None
Effect on soil fertility	Beneficial, especially when branches are pruned and some roots die off (aeration)	None
Erosion control	Can be effectively used as barrier	None
Competition for water and nutrients and light with nearby crop	Does exist but varies according to system; organic matter production compensates	None
Protection of crops and/or animals against wind	Effective but varies according to species height, density	None
'Horizontal rain' (fog drip) from moisture-laden winds	Possible	None
Toxic effects	Possible (allelopathy)	None (except when some preservatives are used)
Harmful fauna	Can be sheltered	None (except termites in some cases)
Beneficial fauna	Provides shelter and food (e.g. birds, honeybees)	Little
Additional economic products	Many, such as food, feed, medicinal products; also firewood, posts and more live fenceposts	None
In case removal is necessary	Difficult and costly	Relatively easy
Labour for management	Periodical pruning is necessary; skills required	Skills also required to place posts and wires and replace them
Acceptance by farmer	Very popular among poorer farmers	Depends on income; more affluent farmers tend to avoid live fenceposts
Special limitations	Disliked by fumigation pilots	Firebreaks must be kept clean during fire season
Aesthetic appreciation	Depends on management and cultural background	Depends on investment possibilities and cultural background

slightly modified from (50)

3.6.4 Species and occurrence

Species Selection

If fencing is the main purpose of hedges, plants are required which

- are of medium height,
- quickly reach the desired height and impermeability,
- are long-lived,
- are non-invasive,
- are easy to propagate by cuttings or direct seeding,
- mature hedges should not seed or spread quickly to become a noxious weed,
- be capable of growing under adverse conditions and close together.

Specific criteria for stockproof fence see 3.6.8.

Species and occurrences

Important species: There are many species suitable for live fences: However, to form really stockproof hedges, the choice is limited. Good management and design makes this statement relative.

Security species for the arid and semi arid areas include *Acacia mellifera, Acacia tortilis, Caesalpina spp., Dichrostachya cinerea, Euphorbia spp., Jatropha curcas, Opuntia ficus-indica, Parkinsonia aculeata, Pithecellobium dulce, Prosopis spp., Ziziphus spp.* In the humid tropics *Citrus aurantifolius, Gliricidia sepium, Leucaena leucocephala, Yucca spp., Aberia caffra, Agave spp., Opuntia spp.* and *Caesalpinia tinctoria* have been successfully used in tropical highlands.

Stock proof or nearly stockproof security fences include *Acacia ataxacantha, Acacia greggii, Acacia mellifera, Bougainvillea glabra, Agave spp., Commiphora africana, Lycium afrum, Parkinsonia aculeata* (for other species see Tables 51, 55 and 57). Only for Southern Africa a comprehensive list of security hedges recommended for trials is available (see Table 13).

Examples of occurrence: Live fences are popular in many countries (366, 365). Their use is a common vernacular practice, e.g. around farm land in Gujarat/India (294), and plantations, e.g. tea plantations in Sri Lanka (218), or coffee plantations in Costa Rica (108). More or less stockproof hedges can be observed in many countries.

In the New Hebrides, the following species were found to be suitable: *Erythrina indica, Hibiscus tiliaceae, Pterocarpus indora.* Nonpalatable plants like *Euphorbia balsamifera* proved to be very suitable for the Sahel (50) (*Euphorbia spp.*and *Prosopis spp.* have proven somewhat resistent to grazing in Somalia, Kenya and Niger) (381). However, even the tops of young *Prosopis chilensis* are eaten by goats, impeding the development of living fences (215a). In the Sahel *Euphorbia balsamifera* is planted at the side from which the stock invades, to protect crop and pasture land. A very dense hedge structure, which inhibits the penetration of stock, can be achieved with the liana *Leptadenia hastata.* This is a valuable leafy vegetable (366a). *Agave spp.* provides suitable protection in savannah climates. Acacia hedgerows or ornamental plants like *Bixa spp., Bougainvillea spp.,* and *Croton spp.* give fairly good protection after a few years of growth.

Before the invention of barbed-wire fencing the expansion of animal production was based on live fences, as in Cuba (77). The Bamileke have developed a perfect hedgerow network for zoning their livestock, mainly of *Raphia* palm species (see Appendix 1).

Table 13: Recommended indigenous security hedge plants suggested for trials in major agroecological zones of southern Africa (166)

Framework plants	
* □ *Dovyalis caffra* * *Dovyalis zeyheri* * *Scolopia zeyheri* * *Ehretia rigida* * *Rhus pyroides* * *Acacia karroo* * *Maytenus heterophylla* * *Scolopia mundii*	*Scolopia flanaganii* *Cassinopsis ilicifolia* *Acacia fleckii* *Acacia tortilis* subsp. *heteracantha* *Acacia davyi* *Acacia exuvialis* * *Scutia myrtina* * *Ziziphus mucronata* subsp. *mucronata*
Fillers	**Entanglers**
Short: *Maytenus polyacantha* *Ziziphus zeyheriana* *Scutia myrtina* *Carissa bispinosa* var. *bispinosa* *Rubus ludwigii* Irritant: *Urtica lobulata* *Smodingium argutum*	*Protasparagus laricinus* *Protasparagus krebsianus* *Protasparagus aethiopicus* *Scutia myrtina* *Rubus rigidus* *Rubus pinnatus*
Fence reinforcers	**Browse-resistant**
Cassinopsis ilicifolia *Rubus pinnatus* *Rubus rigidus* *Scutia myrtina*	*Maytenus heterophylla*
Ornamental	
Flowers and/or fruits and foliage attractive: *Smodingium argutum* *Scolopia mundii* *Cassinopsis ilicifolia* *Aloe arborescens* *Acacia ataxacantha*	Flowers and/or fruits attractive: *Acacia* spp. *Dovyalis caffra* *Dovyalis zeyheri* *Ehretia rigida* *Maytenus heterophylla* (flowers attractive but often have a strong, unpleasant smell)

* prior use as a hedge; □ species which maintain ground density the best.

Framework plants	Fillers
□ * *Lycium afrum* □ * *Lycium ferocissimum* □ * *Lycium oxycarpum* □ * *Dovyalis caffra* * *Ehretia rigida* *Rhus ciliata* □ * *Putterlickia pyracantha* □ *Phaeoptilum spinosum* □ *Lycium hirsutum* □ * *Commiphora pyracanthoides* * *Ziziphus mucronata* subsp. *mucronata* * *Maytenus heterophylla* • * *Acacia karroo* □ • *Acacia mellifera* subsp. *detinens* • *Dichrostachys cinerea* subsp. *africana*	Short: *Lycium afrum* *Lycium ferocissimum* *Lycium hirsutum* *Lycium prunus-spinosa* *Maytenus polyacantha* *Putterlickia pyracantl a* *Acacia hebeclada* subsp. *hebeclada* *Phaeoptilum spinosum* *Nylandtia spinosa* Irritant: *Euphorbia avasmontana* Tall: *Parkinsonia africana* *Lebeckia macrantha* *Lycium oxycarpum*
Entanglers	**Browse-resistant**
Protasparagus laricinus *Protasparagus racemosus* *Protasparagus aethiopicus*	*Euphorbia avasmontana* *Maytenus heterophylla* *Phaeoptilum spinosum ?* *Commiphora pyracanthoides ?*
Ornamental	
Flowers or fruits attractive: *Acacia* spp. *Ehretia rigida* *Rhus ciliata* *Parkinsonia africana* *Maytenus heterophylla* (flowers attractive but often have a strong, unpleasant smell) *Dichrostachys cinerea* subsp. *africana* *Dovyalis caffra* *Putterlickia pyracantha*	Attractive foliage: *Smodingium argutum* Attractive growth form: *Euphorbia avasmontana*

* previous use as a hedge; □ species which maintain ground density the best; • danger: these species may spread.

Framework plants	Fillers
* □ *Carissa macrocarpa*	Short:
* □ *Dovyalis caffra*	*Carissa bispinosa* var. *bispinosa*
* *Acacia ataxacantha*	*Carissa tetramera*
* □ *Flacourtia indica*	*Azima tetracantha*
Phoenix reclinata	*Putterlickia pyracantha*
* *Acacia schweinfurthii*	*Ximenia americana*
Entada spicata	Tall:
* *Capparis tomentosa*	*Balanites maughamii*
* *Pterolobium stellatum*	Irritant:
* *Maclura africana*	*Mucuna coriacea* subsp. *irritans*
* □ *Oncoba spinosa*	*Obetia tenax*
* *Acacia kraussiana*	*Synadenium cupulare*
□ *Dovyalis rhamnoides*	*Euphorbia cooperi*
* □ *Aloe arborescens*	*Euphorbia ingens*

Entanglers	Fence reinforcers
Scutia myrtina	*Acacia schweinfurthii*
Capparis sepiaria	*Acacia ataxacantha*
Capparis fascicularis	*Acacia kraussiana*
Smilax kraussiana	*Entada spicata*
Dalbergia armata	*Pterolobium stellatum*
Protasparagus racemosus	*Capparis sepiaria*
Protasparagus laricinus	*Capparis tomentosa*
	Pisonia aculeata

Ornamental	
Foliage, flowers and/or fruits attractive	Flowers and/or fruits attractive
Aloe arborescens	*Pterolobium stellatum*
Carissa macrocarpa	*Oncoba spinosa*
Acacia ataxacantha	*Gardenia amoena*
Acacia schweinfurthii	*Gardenia volkensii*
Acacia kraussiana	*Dovyalis caffra*
Entada spicata	*Capparis tomentosa*
Oncoba spinosa	*Ehretia rigida*
Foliage and growth form attractive	*Maytenus heterophylla* (flowers attractive but often have a strong unpleasant smell)
Aloe arborescens	
Phoenix reclinata	

Browse-resistant	
Euphorbia cooperi	*Capparis tomentosa*
Euphorbia ingens	*Capparis sepiaria*
Euphorbia tirucalli	

* Prior use as a hedge; □ species which maintain ground density the best.

Framework plants	Fillers
□ ♦ *Euphorbia grandicornis*	Short:
♦ *Euphorbia cooperi*	*Maytenus capitata*
□ * *Commiphora pyracanthoides*	*Maytenus polyacantha*
	Lycium ferocissimum
□ * *Commiphora africana*	*Lycium hirsutum*
□ * *Lycium afrum*	*Lycium prunus-spinosa*
□ * *Lycium ferocissimum*	*Carissa bispinosa* var. *bispinosa*
♦ *Euphorbia tirucalli*	*Carissa tetramera*
♦ *Euphorbia ingens*	*Carissa haematocarpa*
□ ♦ *Euphorbia grandialata*	*Commiphora pyracanthoides*
□ ♦ *Euphorbia virosa*	*Commiphora africana*
□ * *Dovyalis caffra*	*Acacia hebeclada* subsp. *hebeclada*
□ * *Rhus longispina*	*Euphorbia grandicornis*
□ +*Acacia luederitzii* var. *retinens*	*Azima tetracantha*
□ +*Acacia senegal* var. *rostrata*	Tall:
Acacia grandicornuta	*Acacia nigrescens*
Acacia erubescens	*Acacia senegal* var. *leiorhachis* and other *Acacia* spp.
Acacia mellifera subsp. *detinens*	*Balanites maughamii*
Acacia ataxacantha	*Lycium oxycarpum*
+*Capparis tomentosa*	Irritant:
+*Capparis sepiaria*	*Obetia tenax*
□ *Lycium oxycarpum*	*Euphorbia grandicornis*
□ +*Phaeoptilum spinosum*	*Euphorbia ledienii*
	Euphorbia pseudocactus
	Euphorbia cooperi
	Euphorbia tirucalli
	Euphorbia virosa
	Euphorbia ingens
	Mucuna coriacea subsp. *irritans* (in moist places)

Entanglers	Fence reinforcers
Capparis sepiaria	*Capparis tomentosa*
Capparis fascicularis	*Capparis sepiaria*
Protasparagus spp.	*Acacia ataxacantha*
Scutia myrtina	*Scutia myrtina*
	Rhus gueinzii

Browse-resistant	
Euphorbia grandicornis	*Euphorbia virosa*
Euphorbia cooperi	*Acacia luederitzii* var. *retinens*
Euphorbia ingens	*Capparis* spp.
Euphorbia grandialata	*Maytenus* spp.

Ornamental	
Flowers and/or fruits attractive	Flowers attractive:
Terminalia prunioides (flowers and fruits attractive, but flowers have a very strong, sickly sweet smell)	All the *Acacia* spp.
	Gardenia volkensii
	Ehretia rigida
	Parkinsonia africana
Acacia ataxacantha	*Carissa haematocarpa*
Dovyalis caffra	*Capparis tomentosa*
Putterlickia pyracantha	*Maytenus heterophylla* (flowers attractive, but often have a strong, unpleasant smell)
Pterolobium stellatum	
Oncoba spinosa	*Aloe arborescens*
Attractive growth form and/or foliage	
Euphorbia cooperi	*Phoenix reclinata* (in moist places)
Euphorbia tirucalli	
Euphorbia grandialata	*Acacia schweinfurthii* (in moist places)
Euphorbia grandicornis	
Aloe arborescens	*Acacia ataxacantha*

* successful security hedges; □ species which maintain ground density the best; + occasionally browsed; ♦ browse-resistant.

Over 90 species have been identified as livefence supporting wire (51). Some of the most widely used ones in Latin America include *Bursera simarouba, Erythrina berteroana, Gliricidia sepium, Jatropha curcas, Spondias purpurea, Yucca elephantipes.* Throughout tropical Central America over 50 tree species serving as live fence posts have been used over a wide range of conditions. From the South-east of Mexico to Panama *Agave yucca, Brolia cactacea* and many others are common (50,51). In Costa Rica more than 57 have been identifed by SAUER; the 26 most important are briefly described (318). Today the most common plants include *Bursera simarouba, Erythrina spp., Spondias mombin* (51). From Haiti *Anathenium zizarriides, Jatropha curcas* and *Bromelia pinguine* have been reported (244).

Gliricidia sepium is one of the most commonly used species in the more humid regions (2). For this purpose it is planted in Mexico (63), Venezuela, Peru, Guatemala, El Salvador, Sri Lanka (217), and Indonesia (394), the north of Nigeria and other parts of Africa (39), to name a few. *Jatropha curcas*, due to its inpalatability and drought resistence is grown as a fence in many countries like Philippines, Samoa, Antilles, and Angola (208). *Erythrina spp.* is famous in Central America when gardening and security needs are required (214).

3.6.5 Live fence posts - A special case not only in Latin America

Fencing with the help of existing trees is undoubtedly the cheapest alternative, but suitable trees are not always available. Barbed wire is attached to existing trees or cuttings. Large cuttings that root easily are normally spaced at intervals of 1.5 - 3 m. To rely on living fence posts is very common in livestock-oriented pasture land use, as in Central and South America.

Advantages: The relative advantage of live fence posts compared with wooden (dead) fences for the small rancher (summary in Table 12) includes:

- longer lifespan;
- multiple uses in economic and ecological terms,
- less capital-intensive.

Limitations of this type of living fences include the fact that barbed wire is too expensive or that suitable plants are unknown. There may be a shortage of sufficient cuttings. Sometimes soils are too degraded or shallow, which impedes easy establishment of cuttings and quick growth. In areas where there is no natural source of cuttings, supplies may be difficult or expensive (20).

Production of live fence: In Costa Rica a *Gliricidia sepium* fence which is one km long (666 posts) was found to produce 3,600 posts. Posts which were 2.5 m long were harvested after two years (224)

In areas where there is no natural supply of cuttings, producing live posts is important for expanding livestock activities, as in Costa Rica (20) or Mexico. Selling living fence posts yielded an income which was 32 times more than from selling this wood for firewood in the same place (224).

3.6.6 Stockproof security fence

For poor farmers the only viable option is a stockproof hedge without barbed wire, because suitable indigenous plants can make a cheaper fence without some of the limits of living fence posts supporting wire.

Species selection

If the prime or only purpose is a stockproof security barrier the plant should

- be woody or a succulent shrub or low-growing tree;
- be sturdy, multistemmed from the base or low-branching,
- be dense branching with rigid or entangling branches and a spreading crown;
- have small sparsely distributed leaves that will cast little shade;

- have spines, prickles, thorns,
- be resistant to fire, trampling and browsing;
- require little attention or upkeep after planting;
- be capable of regeneration if damaged,
- be irritant as a result of stinging hairs, latex or other agents.

Not many ideal plants exist which have the aforementioned characteristics. Often a mixture of plants are required to fill in gaps and to strengthen the barrier. According to their position, the following categories can be distinguished:

- framework plant;
- fillers;
- entanglers.

Framework plants which form the main frame of the barrier have nearly all the desired characteristics. Short fillers can fill gaps between the ground and the lowermost branches of the framework plants. They should have many rigid branches and be tolerant of shade. Tall fillers fill gaps in and add height to barriers. They should be multi-branched but cast little shade. Entanglers are plants thickening up the barrier as a whole and add to the difficulty of penetration. Suitable plants are prickly climbers which do not cast much shade (165).

Profile and height

Shaping and stock fencing requirement: In the choice of profile and height (see general aspects, Chapters 6.3.4). The only limitation here is that the hedge is high enough and that long-term growth is enhanced as much as possible. A one-meter hedge may be adequate for sheep (breeds differ in their hedge-running ability) (44). Leuca fence is one option (see Figures 17 and 18). Between 1.2 and 1.4 m in height is required for cattle. The A-shape, because it tapers to the top must be left taller than the other forms to keep it cattle-proof (44).

Mature hedge trees are inappropriate

As a limited number of plants grow properly under the shade of a mature hedgerow tree, it follows that the part of the hedge under the umbrella will be weak. In practice this is the case. However with heavy pruning less shade may be created. A hedge of thorn declines in strength rapidly once the canopy of a mature tree is reached. Cattle standing under the tree aggravate the problem by pushing one another against the fence, sometimes in an attempt to secure relief from flies.

Thus, it is often the practice to set post-and-rail fencing under the tree, joining the hedge proper at the point where growth strengthens. But the solution is at best a compromise, and if stock escape from a field, the first place to search for their existing routes is under the trees rather than in the main run of the hedge (163).

Hence, if the main urgent purpose for a resource-poor land user is a stockproof hedge, hedge trees should be excluded. However when trees are valued as an essential resource and no other space is available some sort of compromise is possible.

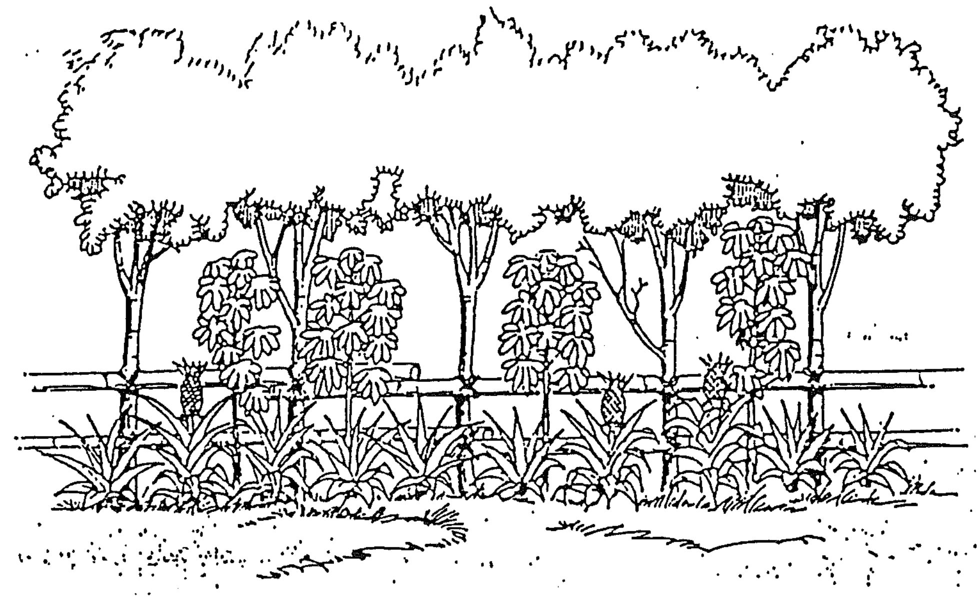


Figure 13: Multistorey garden fence (338)

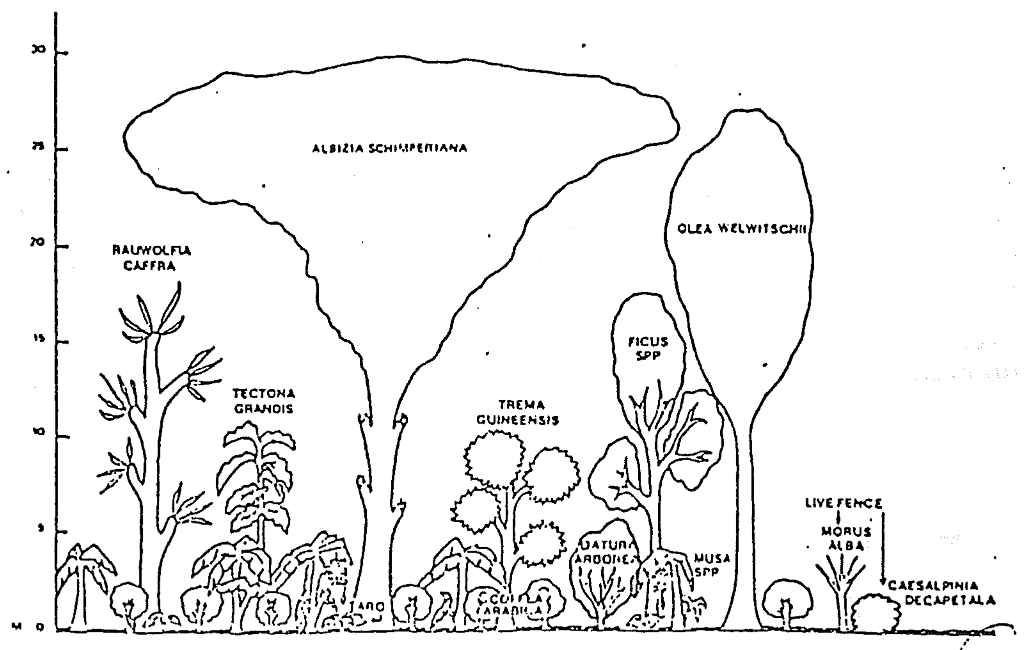


Figure 14: *Morus-Caesalpinia* live fence in a Chagga homegarden in Tanzania (124)

3.6.7 Examples of low cost live fences

Various types of live fences exist. A combination of dead and live fences may be considered as well. The design of a stockproof hedge is determined by what has to be secured (e.g. big/small livestock, theft) and the affordable level of investment.

There are different styles of hedging (e.g. laying, interwoven, etc.), see following examples:

- A firebreak-cum-somewhat-stockproof fence of Sisal and Cassia in Ghana (Figure 15);
- Sheepproof Leuca fence (Figures 17 and 18);
- Bihaya fence to protect fodder trees in Nepal (Figure 19);
- Laying.

Laying is a common traditional practice in England, but hardly tried in the tropics (390). The purpose of laying a hedge is to make a poor hedge into a stock-proof barrier and/or to rejuvenate the hedge plants themselves by encouraging them to grow fresh shoots up from the base of the old stem. There are a number of different ways to lay a hedge. The basic technique of all hedge laying is to cut and slash the main stem of a hedge sideways, intermingling stems and shoots to form a stock-proof barrier; stakes of hedge plants about 40 mm in diameter are driven into the hedge bark between the stems of the cut and placed at intervals of 4.5 to 6 m (for illustration see Figure 79).

Trimming versus laying: Trimming is cheaper and easier while cutting and laying makes an immediate stockproof barrier; but it is much more expensive and time-consuming. Trimming is required regularly, but the vigour of stockproof hedges is gradually reduced by regular trimming. Investment costs of laying are high but there is only a need for laying every 8-10 years (44, 163).

3.6.8 Problems that may occur when growing live fences

Live fences need time to get established and developed. If animals cannot be controlled during this period hedge planting may be a failure or regrowth retarded. For a resource-poor land user planting of a security hedge may be less of a challenge than protecting the young plants from free roaming animals. Suggestions for using electric fences, powered by photo-voltaic units (solar energy) which are replaced when security hedges are well established have not proved viable on a large scale (215a)

Living fences are not always very satisfactory, since they take time to establish, sometimes in more arid regions up to 7-10 years before they form a really satisfactory stockproof security hedge. If not properly managed they may be unreliable due to breaks in the lines or the development of an open base as they mature. Properly managed hedges can have a life span of more than 100 years (77), but hedges may have only a one-year life span when inappropriately managed.

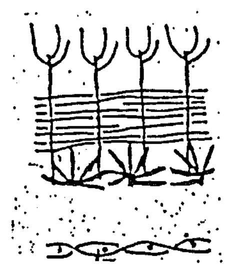
There is no perfect stockproof hedge for all animals (44). Some animals like goats, seem to be difficult to control even when fences are 1.5 m high. They can jump and squeeze through hedges strong enough to contain cattle.

Front view *Side view*

At the foot of local Cassia Sisal (Agave sisalana) is planted closely to form a cheap but very effective fence against squirrels, grasscutters and rabbits, goats, and even cows. After two years Cassia is cut at a height of 1.5 m to develop a bare stem with a crown on the top of it. Hence, Cassia can be regularly pollarded. This barrier can also act as a firebreak to protect farm from fire from adjacent bushes.

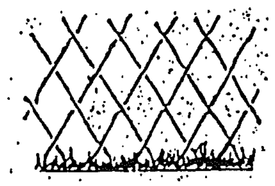
Figure 15: Stockproof cum firebreak Cassia-Sisal fence (369)

Intertwined fence



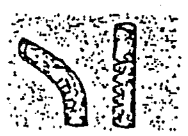
If necessary the fence can be strengthened by intertwining the cut off branches between the stem.

Intergrown living fence



Another possibility is to intertwine the stems themselves.

Forced bend



To ease the banding, scars or incisions can be made at the bending place. The stems are tied together at the crossings.

Crossing grown together

If the bark of the stem is scratched off at the crossing the stems will grow together permanently.

Figure 16: Techniques for making a stockproof Cassia-Sisal fence (350)

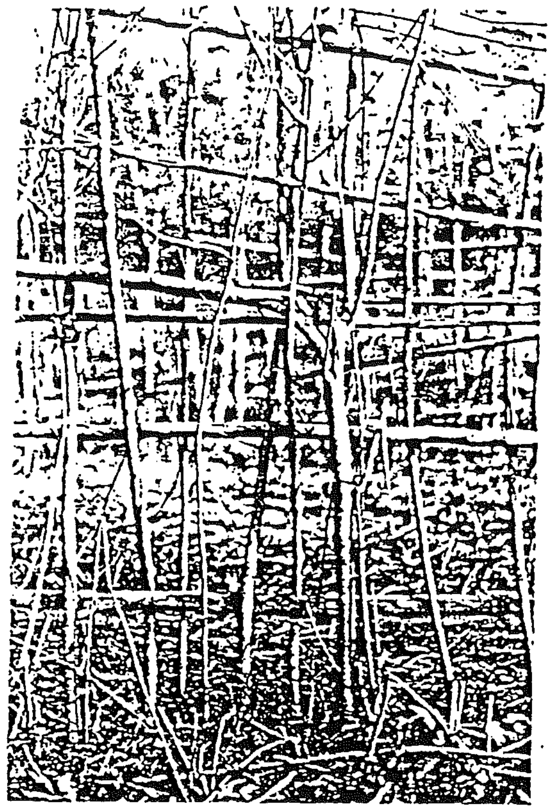


Figure 17: Sheepproof Leuca-fence (349)

Figure 18: West African sheep with triangular neck yokes in a small paddock formed by a Leuca-fence (349)

Leuca-fence is made from closely seeded Leucaena trees (5-15 cm spacing) that are approximately one year old (when stems are 1-3 cm diameter at waist height). The trees are first thinned by cutting about two thirds of them at a height of 1-1.5 m above ground level. During the thinning process, the thickest stems are selected for use as bottom rails. Small branches and stems are then removed from the remaining tall trees.Strong branches selected during the thinning process are bent and woven through the short Leucaena stems and pushed down to about 10-15 cm above ground level. Rails are overlapped for added strength. The bottom rails, for a whole side to the area to be fenced, are laid before any further weaving.The second, third, and fourth rails are woven in the same way as the first; the tall trees are notched with a cutlass, bent over to about 20 cm above the previous rail, and woven into the short Leucaena stems. Gaps in the short Leucaena stems can be filled with sticks obtained from thinning. By notching and bending the rails instead of cutting them, completely, the majority remain alive creating a permanent and durable fence. Leucaena fence has been successfully tested at Ibadan with West African Dwarf sheep. Triangular neck yokes can be used to increase the security of the fence. The lower Leucaena regrowth is grazed, while the upper branches can be used for cut-and-carry feed, stakes or firewood.

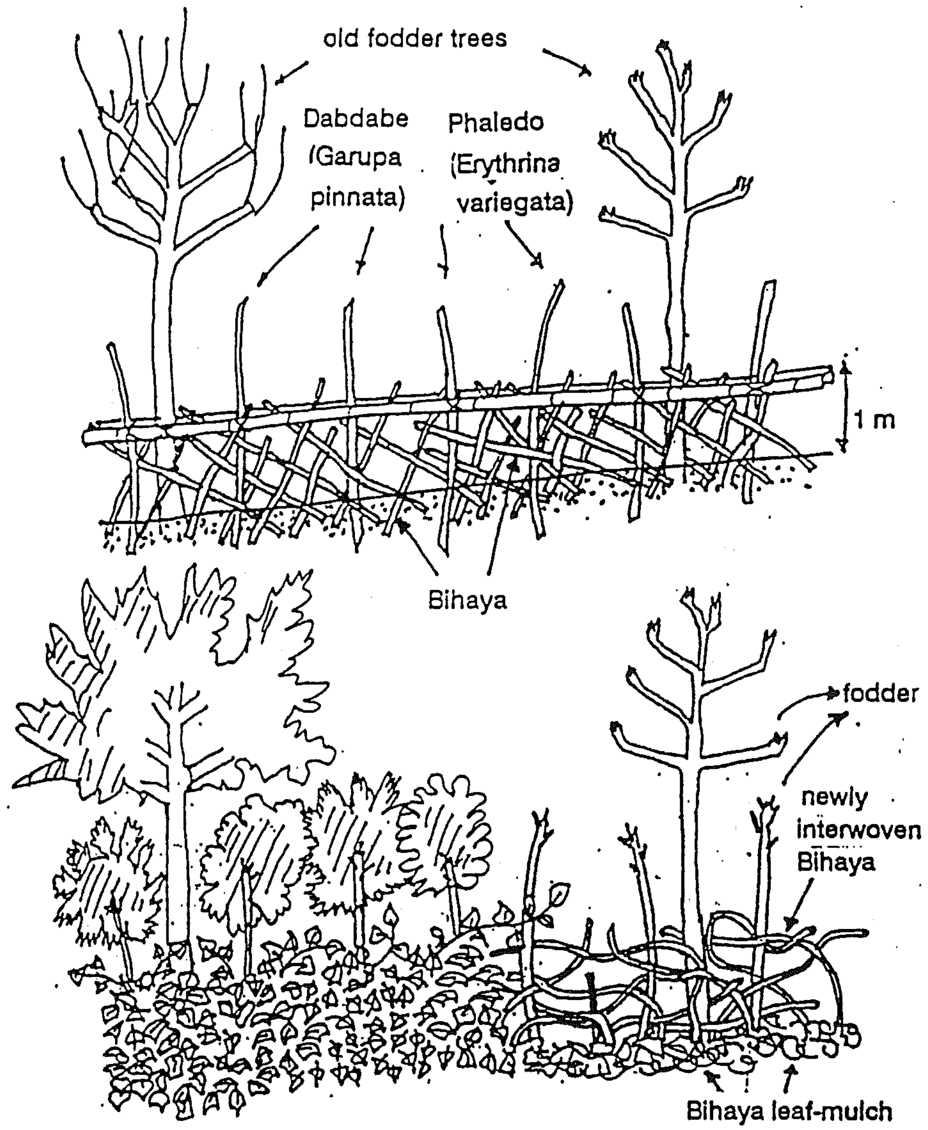


Figure 19: Fodder tree establishment in the Bihaya fence (*Ipomea fistulosa*)

The nonpalatable Bihaya (Ipomea fistulosa) fence is very suitable for protecting newly planted fodder trees in the live fence. Bihaya is a perfect fence because it is very easy to establish, not eaten by any livestock and it provides more than one use. It grows virtually anywhere it is dropped, i.e. cut branches lying on the ground in monsoon will root. The lying branches and shoots are supple and can be woven around. Even broken branches will not suffer, if some of the bark is still attached. Fortunately it does not spread by seeds.

After planting and regular slashing of the Bihaya new interweaving can take place. It is recommended that all leafy mulch be left on the ground on both sides of the fence, because Bihaya could compete with the fodder tree for nutrients. These nutrients can easily be recycled to the roots of the fodder tree, if the leaves are rotting there. Farmers in the plains of Nepal (Terrai) use Bihaya for fencing. Bihaya also grows well in the Himalayas. The leaves are used for green manure on rice fields. Fuel can also be obtained from branches more than 1 year old since Bihaya is not spiky or thorny (22a, 321).

3.7 Green manure/mulch production from hedges

Woody vegetation, particularly forest fallow, is a key in traditional rainfed farming based on low external input. Poor land users are harshly affected by the disappearance of woody vegetation and available land. The various roles of green manure and/or mulch obtained from hedges which are suitable for small-scale farmers are the theme of this part. The impact of mulch on microclimate change, weed suppression and plant protection, soil fertily and net result on crop yield will be outlined. Determinants which affect biomass production from mulch-like planting material and density, spacing, cutting regime and type of application of mulch will be shown. Alley cropping, i.e. a special form of hedgerow intercropping has gained much attention. This prominent cropping system will be discussed in detail.[1]

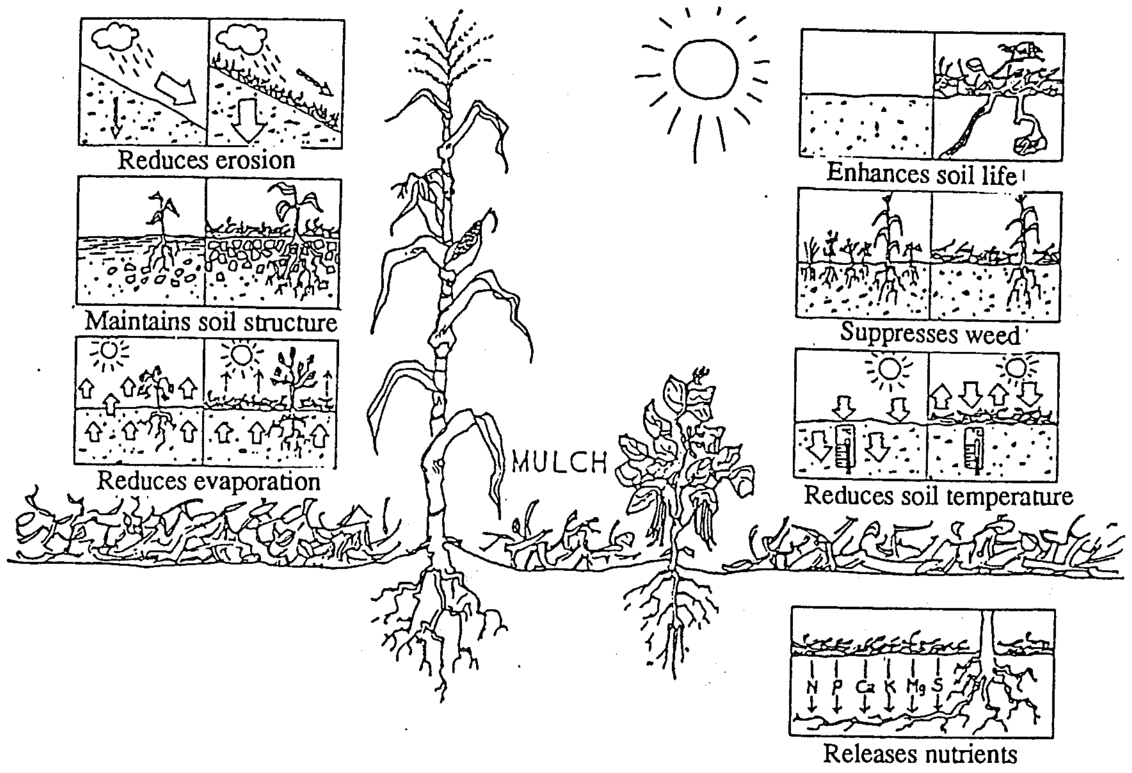


Figure 20: Some impacts of mulch on agro-ecosystems (248)

1 Alley cropping: i.e. systems "in which herbaceous crops are grown between parallel hedgerows of woody perennials. The function of the hedgerows is to sustain soil fertility. It is a term which looks at the system from an agricultural viewpoint only: The 'alley'is where the 'cropping' takes place. In many systems, however, the hedgerows also have a productive role, for instance in terms of fodder, fuelwood or fruit. Hedgerow intercropping offers a more balanced description: it refers first to the distinctive feature, the hedgerows, and then to the cropping that takes place in between them." (188a).

3.7.1 Impact of mulch/green manure from hedges

Mulching can be an appropriate technology for small-scale farmers to reduce the negative impact of rain, hail, and wind (see 3.9), and to control weeds and pests (343). Its attractiveness for poor land users can be to improve the microclimate in the field relatively independently of weather, to reduce weeding costs, and to maintain and enhance soil fertility. The role of mulch in pest management is not well understood. Biomass from hedges can play an important contribution to a more secure, diverse and sustained yield for small-scale farmers. Mulch and/or green manure can be obtained from pruning hedges. A minimum of 5-10 tons of mulch are needed for manuring one hectare of land per year. Sufficient and convenient supply has been one major constraint for wider application, particularly in more arid zones.

Hedgerow cropping (alley cropping) has proved to be a significant source. It refers to cropping systems where arable crops are grown in the interspace (avenue or alley) between hedgerows (for examples of cropping sequences see Figures 21 and 22).

Hedgerows are one interesting approach to partially replacing the forest fallow functions. Hedgerow intercropping can act like a simultaneous fallow or pseudo-fallow. Hedges can also act as a "mulch fence" (106) catching organic matter and debris as it blows around. Collecting of fertiliser with the woven fences is practised in flood land farming in Mexico (see case study in Appendix 1) is another option.

Temperature, moisture, physical and chemical properties, and microbiological activities are influenced by mulch (for impact of mulch see Figure 20). Mulch and/or green manure obtained from hedges can be very important for poor land users by:

- providing a microclimate relatively independent of the weather,
- reducing weeding costs,
- reducing pest and disease problems,
- maintaining and enhancing soil fertility.

Microclimate

The influence of hedges on the microclimate either may be favourable or detrimental, depending on the specific context (343). Conservation of soil moisture, prevention of erosion and maintenance of adequate organic matter are important advantages of mulching (192) (for more on microclimate manipulation see 3.9).

Weed control

Control of weeds is one principal problem in arable cropping. Suppressing weeds is one major advantage of alley cropping in small farms (202). However from a short-term microeconomic point of view the application of herbicides may be more attractive than relying on prunings for hedges. For small-scale farmers this may not be affordable.

In controlling annual weed species the mechanism basic to the success of the leaf mulch is either:

- prevention of germination (in cases where light acts as a trigger in the germination process), or
- stunting the early development of the small seedlings (49)

In alley cropping hedges may occupy up to 50 % of the arable land; this alone can reduce labour input for weeding.

For long-lasting soil cover, mulch matter with a high C/N ratio is necessary particularly in the humid tropics; this is one factor that helps to slow the decomposition rate. Prunings from *Acioa barterii* and *Alchornea cordifolia* (202) and *Cassia siamea* decompose slowly; they are effective when applied in sufficient quantities as mulch for suppressing weed growth (*Cassia spp.* which has a slow decomposition rate may result in lower weeding and pruning costs) (403).

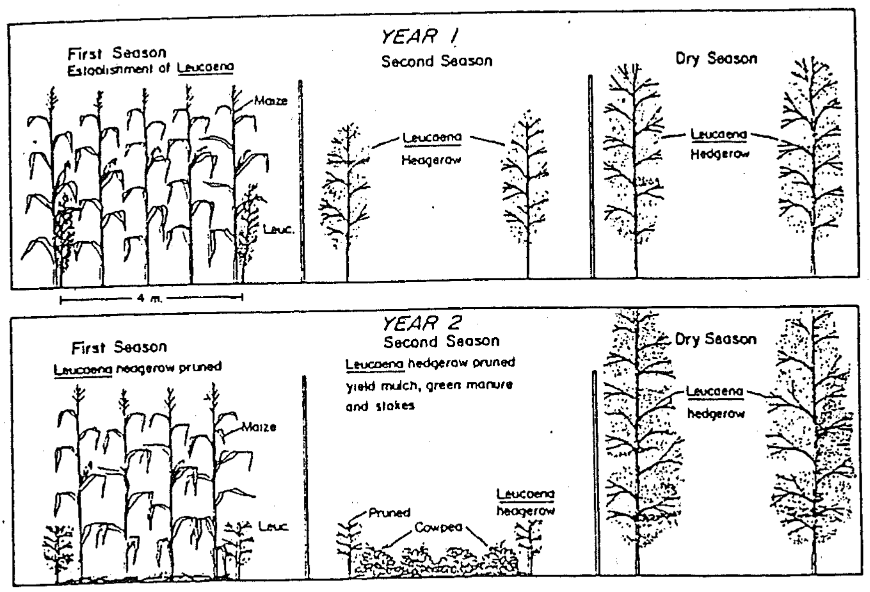


Figure 21: Cropping sequences diagram for establishing *Leucaena leucocephalla* hedgerows (spaced 4 m) for alley croppping with sequentially cropped maize and cowpeas (202)

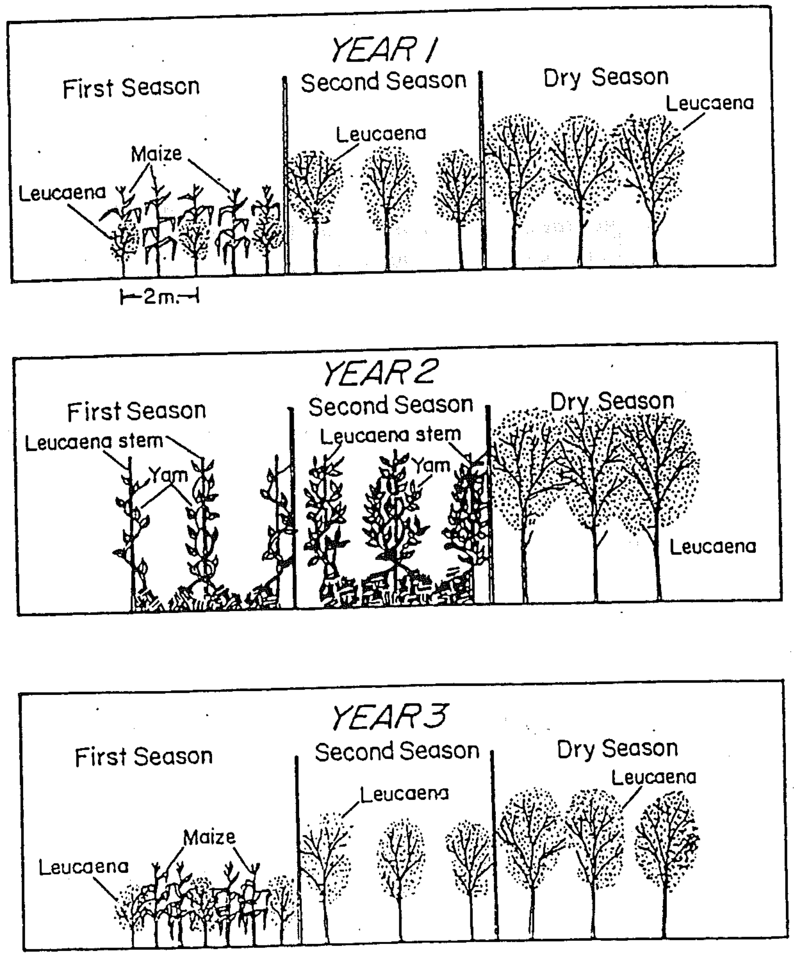


Figure 22: Cropping sequences diagram for establishing Leucaena hedgerows (spaced 2 m) for alley cropping maize and for in situ yam vine support (202)

A study on the performance on the leafy mulch of *Leucaena leucocephala, Gliricidia sepium, Flemingia macrophylla* in weed control in the southern Ivory Coast showed that only *Flemingia macrophylla* showed promise in retarding weed development. For moderate quantities (up to 5 tons of dry leaf mulch per ha) the effective life-span was estimated at about 100 days. The difference in the behavour of the mulches of the respective species regarding weed suppression cannot be attributed to mere differences in the dry matter content. Generally speaking leaves with a low area to weight ratio are relatively resistant to decay.

The success of mulch in weed control depends at least partially on intrinsic or material-specific factors such as its behaviour when drying and the chemical composition of its dry matter. Species like *Flemingia macrophylla* are an example of a source of material that combines a notable durability with a favourable ratio of volume to weight. Compared with other sources one needs relatively small quantities to achieve complete soil cover (49).

Plant protection

Live mulch changes soil conditions and can support a larger soil fauna throughout the year (in dry zones) although higher soil moisture has been observed. Mulch from prunings can lower soil temperature and enhance biological activity (e.g. earthworms). In Sri Lanka it was found that in alley cropping with *Gliricidia sepium* the soil fauna includes general predators (spiders, centipedes, ants, beetles) and predatory bugs. Ecological stability and biological control of soil pests can be created by using mulch. Many parasites and predators pass adverse climatic conditions on the litter of the soil which provides them with shelter (125).

However, application of mulch may transfer pests and diseases. The population of mice and rats may increase. In Timor, dry Leucaena mulch was rejected because it provided a habitat for rodents (286). There may be beneficial as well as harmful fauna due to mulch application from hedges (see 3.11).

Soil fertility

Sharing of nutrients and water between agricultural crops and hedgerows is possible when the hedge tree species have deeper roots than the agricultural crops, and so they presumably tap nutrients and water from different depths and from a larger combined volume of soil. Surface rooting can become a problem because of competition for nutrients and water.

The recycling of nutrients to the surface soil is one of the basic assets of hedgerow intercropping. When nitrogen-fixing plants are used, some of the nitrogen fixed is eventually released to the companion crops through the decomposition of prunings, i.e. leaves and twigs (202). This central assumption that trees can draw and recycle nutrients from the lower level of the soil profile and that the trees can be managed in a way that minimizes competition with the crop has been documented (350).

In hedgerow intercropping, most of the increases in agricultural yield can be attributed more to the addition of organic fertilizer than to the sharing of nutrients (194). Repeated application of nitrogen fertilizer increases soil acidity, but the addition of *Leucaena leucocephala* prunings does not affect soil acidity (202). In more arid regions water competition may limit the application of green manure (212). It is important to note that water balance is the result of percolation into the soil (gain) and water loss by evaporation. The more water the soil can absorb and the less evaporates unproductively, the more water becomes available for the crops and productive hedges.

Crop yield

Various impacts of pruning material of hedges can finally result in a change in crop yield. In alley cropping, a yield increase of 1/3 for maize (153) or even much more can be expected; for upland rice around 50 % (340); even 100 % has been reported. A significant increase in bean yield has been noted in alley cropping with *Erythrina poeppigiana* (268). The increases can be attributed mainly to the addition of organic fertilizer (340). Small-scale farmers need a secure harvest while economizing their main resource: labour. Hence maximising crop yield may not be their prime concern.

Table 14: Potential dry matter and mulch-N contribution from Leucaena hedgerows (350)

Alley width	Total length of Leucaena rows	% of land planted to maize	per ha alley farm		per ha maize	
			DM	Mulch-N	DM	Mulch-N
m	m	%	T/ha	kg/ha	T/ha	kg/ha
1.50	6667	50	7.25	300	14.5	600
2.25	4444	66.7	4.83	200	7.2	300
3.00	3333	75	3.62	150	4.8	200
3.75	2667	80	2.90	120	3.6	150
4.50	2222	83.3	2.42	100	2.9	120
5.25	1905	85.7	2.08	86	2.4	98
6.00	1667	87.5	1.81	75	2.1	86
A	B	C	D	E	F	G

A – Given by Torres (1983)
B – 100/A * 100 = m of Leucaena row in square ha
C – Given by Torres
D – B * 1.08 kg DM ha^{-1} (calculated as 0.45 kg N m^{-1}/0.0414% N in DM = 1.08 kg DM m^{-1})
E – B * 0.045 kg N m^{-1}
F – D * C
G – E * C

Table 15: Estimated maize yields per hectare of alley cropping (350)

Alley width m	Maize baseline production kg ha^{-1}			
	500	1000	1500	2000
	kg maize ha^{-1} of alley farm			
1.50	6439[1] (4829)[2]	5354(4141)	4824(3781)	4522(3642)
2.25	4461 (3430)	3904(3095)	3717(3038)	3683(3096)
3.00	3470 (2696)	3177(2570)	3162(2653)	3261(2821)
3.75	2875 (2256)	2742(2257)	2829(2422)	3008(2656)
4.50	2478 (1963)	2450(2056)	2606(2267)	2839(2546)
5.25	2161 (1728)	2215(1876)	2409(2128)	2700(2454)
6.00	1989 (1456)	2092(1788)	2334(2079)	2633(2412)
A	D	E	F	G

[1] Calculated with 'full' equation of Torres, where: grain/Leucaena-N ratio = 60.445–6.409 ln (baseline maize yield)
[2] Calculated from 'reduced' equation of Torres where grain/Leucaena-N ratios are reduced by 25%.
A – As in Table 14
B – As in Table 14
C – As in Table 14
D – D = B * 0.045 * grain/mulch-N + (500 * C)
E – E = B * 0.045 * grain/mulch-N + (1000 * C)
F – F = B * 0.045 * grain/mulch-N + (1500 * C)
G – G = B * 0.045 * grain/mulch-N + (2000 * C)

State of knowledge on Maize-Leucaena alley cropping: Leucaena-maize is the cropping pattern on which most research has been focused. Collected data (365) from the lowland humid tropics have greatly influenced technical recommendations. This study was based on the assumption that 30 % crop yield increase is necessary to motivate farmers to adopt the new technology. The result of the analysis was that alley cropping is only warranted where the existing maize production level is lower than 1,500 kg/ha . In addition it was assumed that alleys wider than approximately 3 m would probably not be acceptable where the existing maize production level is greater than 1,000 kg/ha (364). Weaknesses in the analysis are assumptions concering the yield and availability of *Leucaena* nitrogen, which has been estimated unrealistically low in the light of new results. Also two potential new technologies (alley farming and high density planting of maize) have been confused. The traditional maize planting density of small-scale farmers is much lower.

Table 16: Estimated maize yields per hectare of alley cropping with 'traditional'maize planting density (350)

Alley width m	Maize baseline production kg ha^{-1}			
	500	1000	1500	2000
	kg maize ha^{-1} of alley farm			
4.0	2240[1]	2366	2646	2991
4.5	2047	2214	2519	2881
5.25	1826	2041	2374	2755
6.00	1600	1911	2269	2661
A	D	E	F	G

[1] Calculated with 'reduced' equation of Torres
A – Same as Table 14.
B – Same as Table 14
D – D = B * 0.045 * grain/mulch-N + 500
E – E = B * 0.045 * grain/mulch-N + 1000
F – F = B * 0.045 * grain/mulch-N + 1500
G – G = B * 0.045 * grain/mulch-N + 2000

3.7.2 What research and development activities exist?

Recently the potential impact of alley cropping on maize yield has been reexamined in relation to the humid regions of West Africa, using more realistic assumptions regarding the availability of organic nitrogen combined with traditional maize planting densities. The results of this analysis showed that hedgerow intercropping may have potential in a wider range of maize yield environments than previously supposed. It can be attractive at all yield levels and alley widths with the exception of alleys wider than 5.25 m in the 2,000 kg/ha environment (350).

Research: The great potential of hedgerows in the soil fertility cycle has attracted the attention of many research organisations and has been promoted by numerous projects. Various research and development organisations have paid much attention to the green manure and mulch impact of hedges (for a brief comprehensive general review with reference to hedges see 248). Hedgerow intercropping (alley cropping) is the subject of research under a wide range of situations. This traditional technology was further studied by IITA (190-193). This institute has identified more than 30 trees and shrubs as hedge candidates. CATIE is experimenting among other species with *Erythrina poeppigiana* and mulch from livefences. ICRAF's main species trial focuses on *Cassia siamea, Gliricidia sepium, Leucaena leucocephala* (255).

Research on manuring hedge plants has favoured lowland humid tropics and *Leucaena leucocephala* (340) and a few other species. Most research is restricted to agronomic research into maximizing biomass production from hedges. Only recently has more attention been paid to socio-economic issues. Many research efforts have been totally outside the context of existing cropping systems and constraints of small-scale farmers. In the past most research projects have studied agronomic aspects in order to maximize biomass or crop yields. Today there are various on-farm trials in progress. Labour economy is one of the most important aspects for small-scale farmers. With regard to hedgerow growing this has not been sufficiently studied (see 4.2).

The narrow concept of soil fertility (basically replacement of macro nutrients, particular nitrogen) has favoured a few nitrogen-fixing trees. The fact that the improvement of the physical properties of the soil, by application of mulch etc. may be more important than the supply of nutrients, has been neglected. The pest and disease effect of hedges has also hardly been investigated. One study conducted in Sri Lanka investigated the made on pest impact of alley cropping (see also 3.11).

With all these restrictions, implementing development organisations promote only a few species that are either proven or assumed to have been tested: Awareness of the need to diversify species is growing. Today various suggestions have been made to develop and intensify alley cropping to permit more significant ecological and economic interactions (see e.g. 273a).

3.7.3 What species for green manure/mulch

Species selection

The ideal species should be

- fast-growing,
- tolerant to pruning,
- able to coppice vigorously,
- able to produce good mulch/green manure.

In addition, such plants should

- have high foliage production,
- have vigorous tap root development,
- be adaptable to adverse sites,
- be not too woody,
- have an effective long-life span of the mulch (durability with a favourable ratio of volume to weight).

Generally, they should be compatible with agricultural crops. Species which are very suitable for marginal and/or degrading sites are very much needed, because poor land users have to cultivate these sites. Maximising biomass for producing organic fertiliser has to be balanced with other considerations like optimising labour.

Well known species

For the humid tropics trees and shrubs like *Erythrina spp., Flemingia macrophylla, Gliricidia sepium, Inga spp., Leucaena leucocephala spp.* have been proved useful hedge plants for production of organic matter; *Butea monosperma, Cajanus cajan, Cassia spp., Pterocarpus spp., Prosopis spp.*, are applied in semi-arid areas. *Erythrina spp., Tephrosa vogelii,* and some *Cassia spp.*, are used as mulch in tropical highlands (more species see Tables 51 and 53).

In alley-cropping, hedgerow species include *Acacia spp., Albizia spp., Calliandra spp., Cajanus cajan, Acioa barterii, Alchornea cordifolia, Tephrosia candida, Cordia alliodora, Albizia falcataria, Treculia africana, Parkia clappertonia, Flemingia macrophylla* (syn. *F. congesta)* (248, 273a). *Cajanus cajan* seems to be one of the most promising plants which turned out to do very well on sites where other species like *Leucaena leucocephala* show poor performance. An enormous range of varieties and cultivators exist for species like *Cajanus cajan*; this makes a general statement of quality of limited general value. After the severe Psyllid attack on *Leucaena leucocephala* several efforts are being made to replace this plant.

Occurrence: Applying prunings from hedges as fertilizer is a common vernacular practice among farmers in the tropics. (248). As green manure *Sesbania spp.* is unsurpassed in moist environment. *Sesbania grandiflora* and *Sesbania speciosa* are planted on field margins and periodically opened for greenleaf manure in many parts of Asia. It is very common in Java (394), and observed in Sri Lanka (218). *Tephrosia vogelii* hedge seems promising on heavy soils (248).

Today alley cropping is promoted in many countries today. With regard to the hedgerow, there is a need to diversify species and a use of multipurpose trees, mixture of species, and more selective prunings (more see 6.4.10).

3.7.4 Mulch production from hedges

Biomass: There are great variations in biomass production, particularly at farm level. Real farm trials in Nigeria showed that biomass yield in alley cropping varies from 1.3 to 5.4 t/ha over an 8-month harvesting period (204). There can be a great difference between harvestable and recycling biomass. This difference has been neglected by many studies.

In India it was found that 454 *Gliricidia sepium* trees grown along paddy rice field bunds and harvested once or twice a year met the green manure requirements of one hectare of paddy rice (394). In Rwanda *Tithonia sp.* and *Leucaena sp.* produced a considerable amount of biomass. *Calliandra callothyrsus* and *Euphorbia spp.* planted in a double hedgerow gave the highest yield with 10 tons/ha (see Table 44). Well-established *Leucaena leucocephala* hedgerows (on sandy soils, alley width of 4 m) provided between 15 and 32 tons of fresh prunings per year (or 5-6.5 tons of dry matter), gathered in five prunings (excluding stakes). These prunings yield over 160 kg N, 15 kg P, 40 kg Ca, and 15 kg Mg per ha per year (202).

Nitrogen fixing at a level of 500 to 600 kg N/ha/year has been reported from Hawaii (153). In the humid tropical lowlands one meter of *Leucaena leucocephala* planted closely in a hedgerow can produce 1 kg of leafy dry matter per year, with a nitrogen content of 3.5 % and an increase in maize production of 5.3 to 6.3 kg per kg of nitrogen prunings. In the Philippines, alley-cropping trials with *Leucaena leucocephala* (20 % of the field) with 10 harvests per year produced 291 kg of N, which is equivalent to 12.7 bags of urea (379). As previously shown, the absolute amount of biomass available for mulch is a very restricted parameter.

Table 17: Comparative effects of alley cropping (340)

Tree species	Agricultural crop	Alley width (m)	Tree herbage yield ($kg\ ha^{-1}$)	Total nitrogen yield ($kg\ ha^{-1}$)	Agric. crop yield ($kg\ ha^{-1}$)
Acioa barterii	Cowpea	2	–	–	1043
		4	–	–	1637
Acioa barterii	Maize	2	–	–	1249
		4	–	–	1620
Alchornea cordifolia	Cowpea	2	–	–	740
		4	–	–	1626
Alchornea cordifolia	Maize	2	–	–	1154
		4	–	–	1527
Gliricidia sepium	Maize	2	–	–	299
		6	–	–	448
Tephrosia candida	Maize	2	–	–	1206
		6	–	–	1453
Leucaena leucocephala	Cassava	1	18200	–	4000
		3	87200	–	19300
Leucaena leucocephala	–	2.25	1084	45.5	–
		3.75	651	27.3	–
		6.75	361	15.2	–
Tephrosia candida	–	2.25	600	22.8	–
		3.75	360	13.0	–
		6.75	200	7.6	–

Table 18: Physical benefits from hedgerow intercropping with *Leucaena leucocephala* (340)

		Nutrient production ($kg\ ha^{-1}$)				Yield of agricultural crop with ($kg\ ha^{-1}$)		
Country	Agricultural Crop	Green leaf organic matter	Nitrogen	Phosphorus	Potassium	Prunings	Mineral fertilizer	Control
Philippines	Paddy rice	–	–	–	–	4500–4800 (dry season) 6200–6900 (wet season)	–	5500–5600 (dry season) 6200–6900 (wet season)
Philippines	Upland rice	1500–2000	60	–	–	4340	4470	1910
Philippines	Maize	–	–	–	–	3000	Almost as with prunings	–
Philippines	Cassava	39800	–	–	–	19300	–	40600
Ghana	Yam	–	–	–	–	5520	–	8640
Ghana	Maize	–	–	–	–	3064	–	5616
Nigeria	Maize	5000–8000	180–250	–	–	3800	5000–6000	1900
Hawaii	Maize	2030 (Single rows) 2230 (Double rows)	60–180	–	–	2390	–	1840
Hawaii	Maize	150	–	–	–	4870 (prunings incorporated) 3570 (prunings mulched)	–	415
Colombia	Maize	8200–17800	81–172	6–13	45–99	4500–6000	–	5400

[1] Green leaf manure or nutrient content on dry weight basis
[2] Data is mean of 4 seasons of harvesting the hedgerow
[3] Note reduction in cassava, yam or maize yield due to shading
[4] Amount of total dry matter depended on cutting time and number of Leucaena rows
[5] Data on nutrient content includes branches besides leaves, and mean for population of 13 000–40 000 leaves/ha.

3.7.5 Hedgerow intercropping (alley cropping) - the prominent example for managing hedges for mulch and green manure

Various management aspects including hedge intra- and inter-row distances, methods and timing of pruning, cutting height, have to be considered. Which method has to be applied depends of the tree species, and the purpose of the hedgerow. For example, if weed management or soil moisture conservation is the main goal, pruning of slowly decomposing hedge plants (with high C/N ratio, important in the humid tropics) may be applied as surface cover. In other words, when the behaviour of a certain mulch material is known, mulching - like any other cultural practice - can be optimised so as to perform beneficial functions at critical stages in the life-cycle of crops. Decomposition trials provide useful information on certain properties of woody species. If a tree species efficient in accumulating potassium (in potassium-poor environments) is required, then one choice may be *Leucaena leucocephala* and *Gliricidia sepium*. If a lasting soil cover for water conservation (unreliable rainfalls) is the main purpose of mulch *Flemingia macrophylla* will be the better choice (49a).

Planting material

The stake establishment method is traditionally applied for live fences. These methods are simple but suitable mainly for situations where only a few trees are to be established, such as for fence posts and shade. When intended for use in alley cropping where tree populations of 10,000-50,000 may be required, stake establishment becomes costly, inconvenient and impracticable. For such a situation seed propagation appears to be the most convenient and reliable means of establishment (18).

Intra-row spacing (planting density)

With direct sowing, a wider range of tree densities can potentially be obtained than with stake propagation. Since the trees in alley farming are usually not allowed to grow very tall in order to minimize shading of the accompanying crop, a high tree density might be expected to be more productive than lower densities. Trials with *Gliricidia sepium* showed that seed establishment with close planting at about 10 plants offers advantages over wide intra-row planting (18). This was confirmed by experiments carried out with *Calliandra calothyrsus* planted with varying in-line spacing. It indicates that closer spacing produces more biomass (see Table 42).

In Maize-Leucaena alley cropping it was found that 5 plants per running meter was the optimum density to maximize biomass (20 plants did not improve the yield of the agricultural crops) (248). Natural thinning may occur at high densities. There is also the problem of woodiness. Hedge plants like *Cajanus spp.*, *Sesbania spp.*, *Tephrosia spp.* are inclined to get woody when planted at wider inter-row distances. Dense planting can prevent the stem getting too woody. Another advantage is that this herbaceous-like stem can easily be cut and better incorporated into the soil. Hence labour inputs decrease and work is easier to perform (262).

Inter-row spacing in alley cropping

Choice of alley width must be based on a number of related factors including potential mulch yield and anticipated effect on crop production, labour requirement for tree pruning, required changes in cropping patterns and ease of management, particularly related to pruning, land preparation and weeding. In farmer-friendly alley cropping, smooth management especially with regard to pruning and potential crop shading should be of primary importance. It is obvious that with narrow alleys between 1 and 3.5 m, the maize population per hectare of alley farm must be reduced.

However, this is not the case for alleys wider than 4 m. Traditional maize spacing (1 x 1) can be easily maintained with 4 m alleys by having a *Leucaena* row after every fourth maize row (the *Leucaena* occupies part of the 1 m wide space between the adjacent maize rows). In this situation the whole alley farm can be considered as the area actually planted to maize (18). In areas with less favourable rainfall or where mechanization is introduced, wider alley width has to be considered (340) (some of the comparative effects of alley width are given in Table 17).

Cutting height

Low cutting (15-30 cm) avoids shading of an associated agricultural crop, particularly when alley width is narrow. However, hedgeplants like *Leucaena leucocephala* may split easily, leading to attack by insects (372). For *Cajanus cajan* the height should be at least 50 cm. For high leafy biomass yields (and with wider alleys), higher cutting is desirable. The taller the stems, the more plentiful the regrowth of branches will be, many of which would have been eliminated by lower cutting. Hence, for green manuring, higher cutting is preferable (340).

A medium height may be appropriate, making annual pruning convenient for the farmer. Also low cutting may be necessary to avoid shading. This is particularly important when the farmer cannot assure cutting at the appropriate time (e.g., when he/she is forced to migrate temporarily during the off-season in search of an off-farm job) (215). To economize labour inputs, a low cutting height (approx. 25 cm) is preferred by many farmers, as in the Philippines

Cutting frequency

Pruning has to be adjusted according to the growth rate of the hedgerow species and its main purpose. The timing for harvesting biomass depends on the site and the farmer's strategies (needs and constraints). In the Philippines it was suggested that *Leucaena leucocephala* should be allowed to grow at least 6 months before initial harvesting. This enables the hedgeplant to have a well-developed root system which withstands drought and promotes rapid regrowth after subsequent cuttings. In semi-arid areas, *Leucaena leucocephala* needs more time to produce harvestable growth (340).

More frequent cuttings during the initial year of establishment had a negative effect on the yields of *Gliricidia sepium* in later years (67). A general rule is that the lower the hedgerow and the taller the crop, the less frequently pruning is needed. Fast-growing hedgeplants like *Gliricidia sepium* and *Leucaena leucocephala* may require pruning every 5-6 weeks during cropping periods. Pruning too often should be avoided, as it may result in diebacks.

Generally the percentage of leaves decreases with increasing harvesting intervals. Species respond differently to frequent cuttings. Studies of coppicing ability indicates that *Gliricidia sepium* grows faster than *Cassia siamea* and *Flemingia macrophylla*. This may impose more shading and therefore more frequent prunings in Gliricidia alley cropping systems. More frequent prunings result in higher production cost. For *Cassia siamea* hedges one heavy pruning before sowing of the food crops will be sufficient .

Type of application

The lower efficiency of prunings applied to the surface (e.g. *Leucaena leucocepphala*) may be due to N volatilization during decomposition. Hence, residue persistence is an indicator of the value of the litter as mulch, weed control and moisture retention during crop growth (202). In areas where rainfall is scarce and conservation of soil moisture is of paramount importance fresh herbage is better than dry, in terms of nutrient utilization by the crops (340). The conventional approach (as investigated) is to use top branches for manure. However, the shedding method reduces labour considerably. In this method, successfully applied by farmers in the Philippines and Indonesia, one girdles or removes a 20-cm-wide strip of bark on the trunk, 1.5 m above the ground. Within one month the leaves dry and fall. Shoots grow back from the trunk below the girdled area. Only three shoots should be allowed to grow (300). Mulch may be carried away by surface run-off during periods of heavy rains, especially in hilly areas. In windy areas, prunings can be blown away by wind or attacked by termites. In this context, the incorporation of prunings into the soil is a better option. Appropriate mechanization in combination with minimum tillage is another important improvement (212).

To sum up: It is ultimately of little value, for example, to investigate various pruning regimes which attempt to maximize the amount of mulch produced, when under farm conditions time and frequency of pruning are determined rather rigidly by the need to minimize shading of the crop. Similar the height of pruning will probably be determined more by considerations of ease and speed than by the effect of pruning on regrowth and tree longevity (350).

3.7.6 Problems that may occur when growing hedges for green manure/mulch

Applying organic manure from hedge plant prunings has some problems. One is gathering enough prunings for effective manuring. This is not the case with alley cropping apart from the dry regions.

The bottleneck of alley cropping may be: Farmers must allocate land and labour to trees which will produce no income during the first season or more. The high amount of labour input in comparison to the bush fallow may not be justified. Further immediate effects are not visible. The incorporation of green manure may be difficult without appropriate mechanisation (212; for some tools see 395). Mulching is tedious work, when sometimes 5-10 tons of mulch are needed per hectare per year. However, the amount of labour may decrease significantly once the hedges are established (89).

The recommendations of research results in alley cropping require a fairly strict adherent planting and pruning schedule in order for the technique to give good results This can conflict with other needs and priorities. The use of biomass for mulch has to be weighed against other uses, e.g. animal feed. Removing parts of the prunings for fodder can reduce agricultural yield. This must be justified by higher livestock productivity to compensate for any loss of crop yield.

3.8 Hedges for water erosion control

Erosion is a very serious problem, particularly in highlands and more arid regions. Within certain limits woody vegetation can prevent soil loss through wind or water action. Prior to discussion of potential roles of hedges for controlling water erosion and wind erosion (see 3.8.3), the relationship between "pressure of production" and degradation of the natural resource base is noted. Why and how efficient hedges can contribute to erosion control and ways to achieve this will be discussed in detail.

3.8.1 Why are hedges suitable for combatting water erosion?

Potential role of hedges

One way to conserve soil and water is by terracing the slope. This is skilfully practised in many countries. However, it requires a high labour input; e.g. establishment of bench terraces can be up to 570 working days per hectare. Poor farmers cannot afford to invest in expensive conservation activities. They lack the capital to tide them over a temporary drop in income. The required time for conservation activities can prevent them obtaining paid work (60).

Hedges and/or mulch from hedges can contribute to soil conservation by reducing the negative impact of

- splash erosion: reducing the size and energy of raindrops in the immediate vicinity of the hedge;
- flowing water erosion on slopes: decreasing the drainage speed and increasing infiltration;
- solifluction: stabilizing slopes mechanically through their roots and by improving the water balance simultaneously.

Factors determining control of water erosion, means of erosion control, and cropping techniques related to hedgerows for soil conservation are summarized in Figure 23.

Depending on the site and the constraints and needs of the land user, the impact of hedges varies. Supplementary physical engineering may be required on steep slopes particularly with a low infiltration rate. Also bench terraces can be stabilized by hedgerows (300).

Living terraces

Where hill farming is practised the most likely way that trees and shrubs can halt erosion caused by water is by planting contour strips or rows. A contour hedgerow also called barrier hedgerow, means a hedge planted along the contour on sloping land with the primary purpose of erosion control. The main difference between alley cropping (strict sense) and contour strips is that strips are bands of multilayered vegetation several meters wide, while alley cropping consists of one or two rows. Although strips provide better protection, the impact of hedgerow intercropping can be very significant. When pruned branches are used to establish trash ridges anchored by the hedge trees or if the hedges are very dense, they may form an effective barrier to catch sediment from cropped slopes (see Figure 24).

In the Philippines a project first planted one row of *Leucaena leucocephala*. But if several trees did not grow so well, there was a hole in the dyke for soil to wash through. Finally two dense rows just half a meter apart made a reliable hedge and the soil that washes off the slopes can build up against the hedge to make the terrace

To enrich the soil and effectively control erosion, stalks, twigs, branches, leaves, rocks, and stones are piled at the base of the thick rows of trees. Gradually permanent and naturally green terraces will be formed which hold the soil in place (352). The strips between hedges tend to alter over the years, becoming a series of terraces with hedges as risers. Internal erosion between the contour strips leads to the formation of induced terraces reducing the slope gradient substantially. The run-off water deposited its soil load at the bottom side of the cropping alley. Terrace profiles developed quite rapidly. On some sites the difference in level from the upper side of the hedge to the lower side was as much as 1 meter

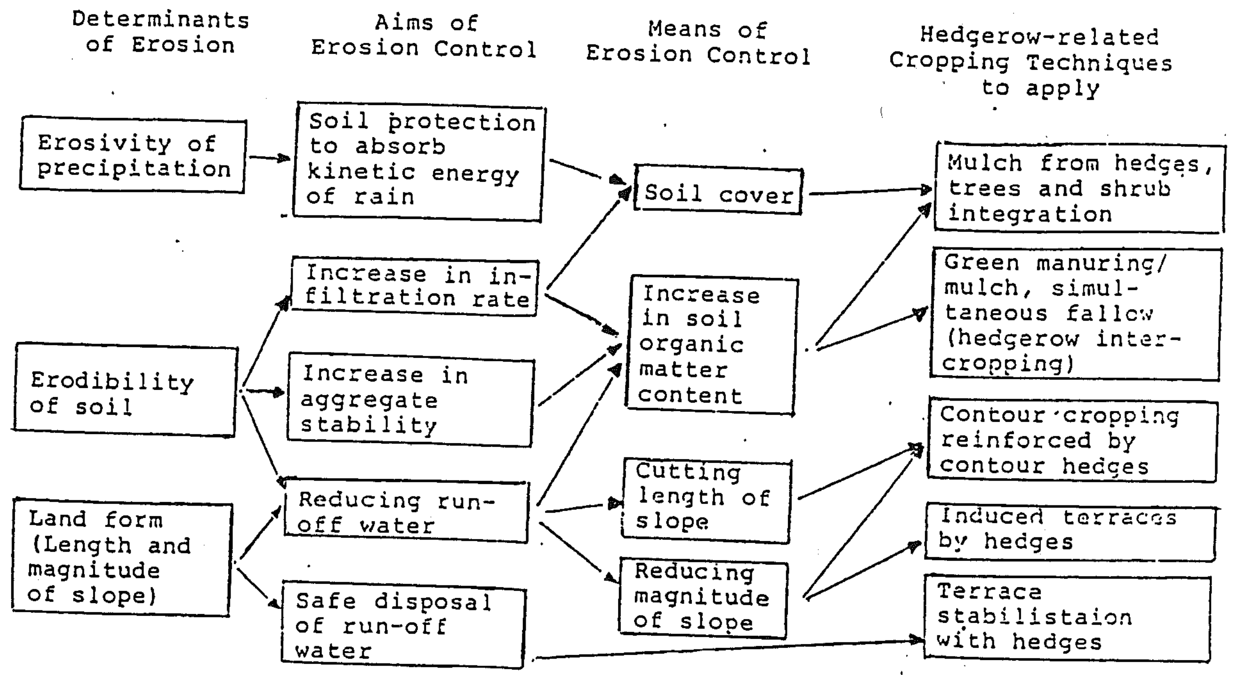


Figure 23: Soil erosion control by water - aims and means of erosion control and cropping techniques related to hedgerow growing for soil conservation

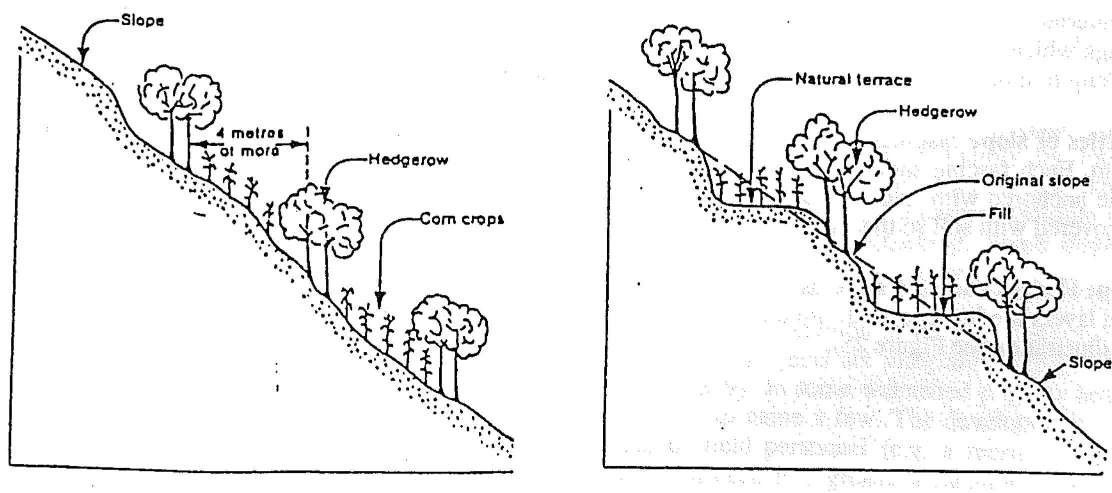


Figure 24: Contour hedgerow intercropping (278)

In brief: Within certain limits living terraces made of contour hedges can be effective means of conserving soils on slopes; this may be almost as effective as terracing, but much cheaper and less labour intensive and produces useful products (371).

3.8.2 Slope (ravine) stabilization

Biological soil stabilization

Soil stabilization methods should be used when dangerous, tensile, impressive mechanical forces threaten to develop in the ground; in such instances, deep reaching stabilization of the soil is needed immediately. Effectiveness begins with root development, followed by increased plant growth, and is then intensified proportionately with the development of the roots and shoots.

Methods

Following methods are widely used:

- Wattle (wicker) fences,
- Cordon construction,
- Brush wattles or slope fascines.

Wattle (wicker) fences: Wooden pegs from 3 to 10 cm in diamter and 100 cm in length, are driven into the ground approximately 100 cm apart. Between these, shorter pegs or cuttings are driven into the ground at approximately 30 cm intervals. The pegs are then interwoven and wrapped with long flexible live branches of a species which is known to root easily from branch fragments (e.g. *Salix spp.).* Each live branch must be pressed down after being woven around the pegs. Normally, three to seven parts of branches must be placed above one another.

Cordon construction: Cordon construction after Couturier is actually a hedge planting or foreste contour row. Pioneer plants which are highly resistant to coverage should be chosen. Willow cuttings are most often used in endangered slope areas. First off all a horizontal terrace is prepared near the toe of the slope. The soil which was removed to build the first terrace is dumped onto the toe of the slope. The steeper the slope the narrower the terrace must be. The distance between them depends primarily on the soil material and its tendency to slide. The Cordon construction by Praxle is a cross layer of coniferous branches planted on a Couturier terrace. For stability poles of some dead material are placed horizontally, underneath the branches close to the edge of the terrace. This layer is then covered with a soil layer and willow cuttings are placed side by side on this soil layer at a distance of 2 to 3 cm from each other. Then the cuttings are covered with soil.

For the Couturier methods three rooted seedlings of trees or shrubs are needed for every meter of cordon, plus 2 to 5 cuttings which must be at least 10 cm longer than the width of the terraces. 10 to 25 cuttings with a minimum length of 60 cm are required for each terrace, assuming a minimum terrace width of at least 50 cm.

Brush wattles or slope fascines: Fascines of living woody plants are laid in ditches with a width and depth of 30 to 50 cm. Each fascine should consist of at least five branches with a minimum diameter of one cm. The fascines are anchored with live or dead pegs, placed at 80 cm intervals. Immediately after planting the ditches are again covered with soil so that only a short section of the branches protrudes from the ground.

To sum up: Hedges can also serve as an effective tool for reforesting ravines and stabilising slopes. Basically brushwood layers are incorporated into the soil. The great advantage of this method is the high rooting capacity. (322) (for illustration see Figure 25).

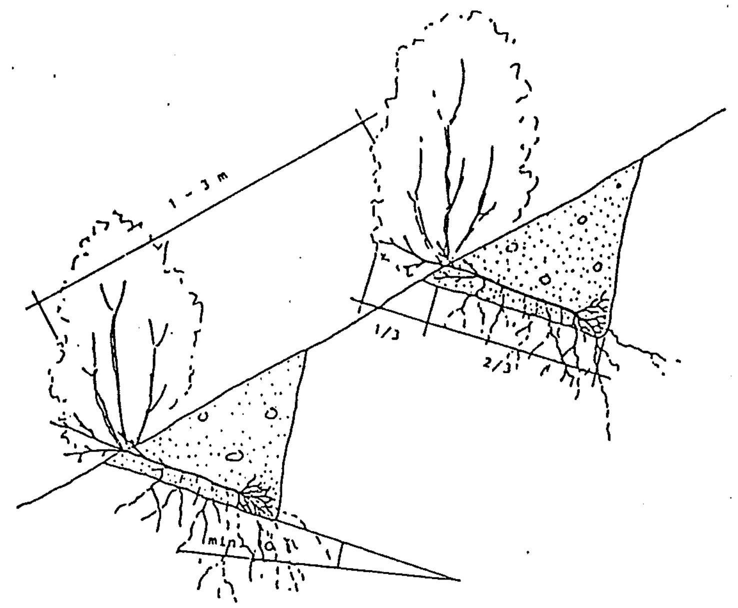


Figure 25:Slope (ravine) stabilisation with the cordon construction (Courturier method) (322)

3.8.3 What research and development activities exist?

Research: The potential role of woody perennials in reducing run-off is increasingly appreciated but not well documented scientifically (141). The few studies which assess the soil conservation impact of contour hedgerows in hill farming have proved the great impact of hedges (e.g. 271,278).

Development: In the past the great majority of natural resource management projects (land conservation, watershed management) relied on physical engineering, and were implemented mainly by food-for-work programs. Today these programs are virtually synonymous with terracing and other labour intensive soil conservation promotion schemes. The high maintenance costs of these physical measures (seldom included in projects) and their relative poor spreading effect have led to a gradual rethinking. Some implementation organisations view the planting of contour hedges of *Leucaena leucocephala* as a panacea.

Hedges for soil erosion control are promoted in countless projects. Promotion of contour hedges relying on a few well-known species is the present trend. Various ecofarming projects are integrating hedges in tree-band planting (strip), e.g. in Rwanda (263), Togo (153a), Tanzania 319). In some watershed projects hedges play a prominent role, e.g. in Cape Verde, Papua New Guinea (148), to name a few. The development of extension material has not responded sufficiently to this new need of field personnel (e.g. a recent FAO manual on vegetative methods (322) hardly mentions hedges). What is needed is a greater awareness of ways in which vegetative methods can be used interactively with physical methods (381).

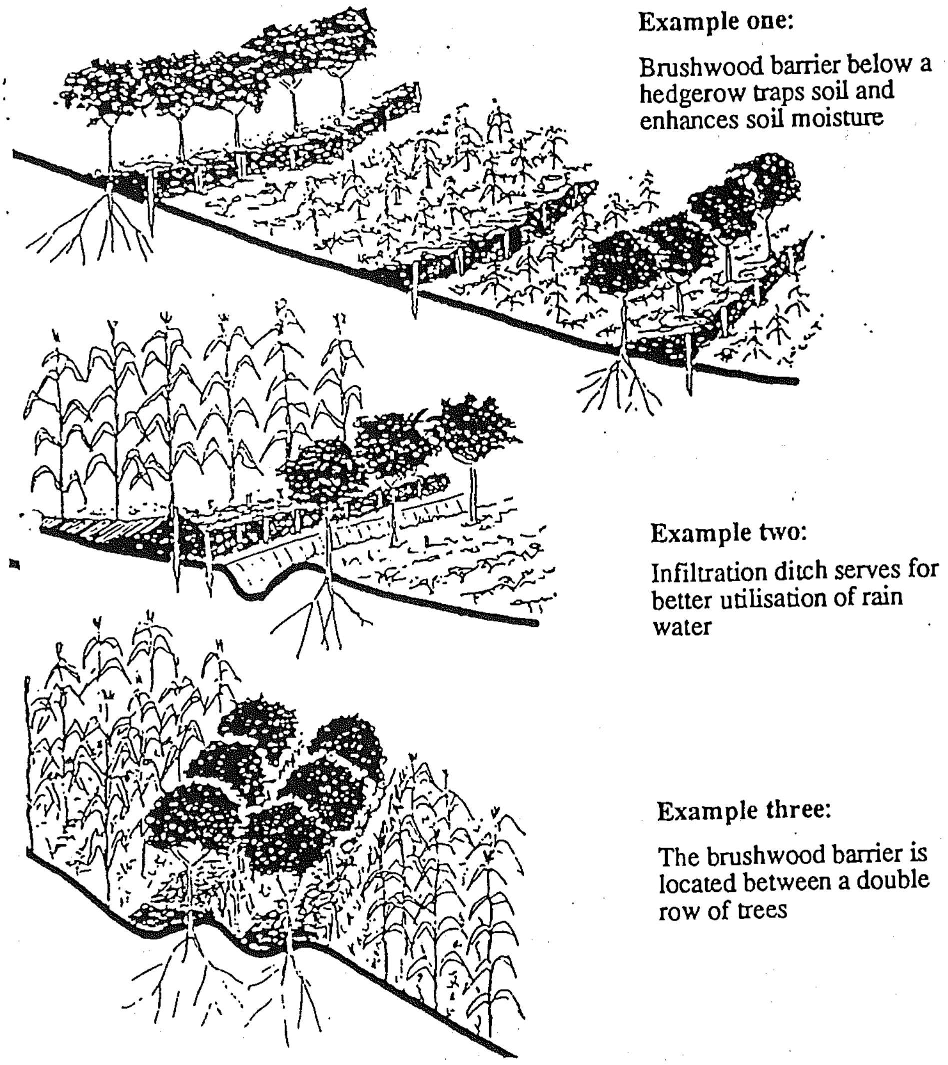


Figure 26: Some conservation methods (brushwood, infiltration ditch) (386)

The establishment of hedges on hillsides in (semi)arid climates requires a number of complementary structures such as brushwood barriers, infiltration ditches, dry wall or bench and micro terraces. They provide a better utilization of the rainwater which collects and infiltrates along the line of trees. As a result, the growing rate of the tree can be accelerated and a more favourable microclimate created, especially during long drought periods.

3.8.4 Grass hedges - the case of Vetiver grass-based soil moisture conservation cum erosion control in-situ

Soil moisture conservation is fundamental to rainfed agriculture. Although the book focuses on trees and shrubs, the role of grass hedges should not be underestimated and deserves special attention. This can be examplified with Vetiver (*Vetiveria zizanioides*). This plant is claimed to be the grass with the greatest potential for soil and moisture conservation for tropical and subtropical regions.

Ecology of Vetiver: The Vetiver grass, which exhibits a wide range of adaptability from sea-level to over 2000 m in the Himalayas, can be found between latitudes 22 degrees North and South, where there is a permanent waterbody. The plant is extremely drought-resistant. Slips for planting have withstood 60 days without rain. In arid areas it is essential that hedges are formed on the contour to ensure their survival by intercepting all run-off. In arid areas Vetiver hedges take three seasons to establish, but once established they are permanent (in the humid tropics, hedges are established in five months). An established Vetiver will completely stop sheet erosion (i.e. erosion of the superficial layer of the soil). Rather than concentrating run-off water into streams and so becoming more erosive, vegetative hedges slow run-off, spread it out and filter out the silt while letting the water out through the entire length of the hedge, but not allowing it to concentrate anywhere. Silt trapped behind the grass barrier spreads back across the field. Vetiver grass grows through the silt in its immediate surroundings, so over the years forming a natural terrace. In Fiji, for example, terraces three to four meters height have formed on 50 % slopes behind the grass hedges. This is soil that would have been lost to the farmer.

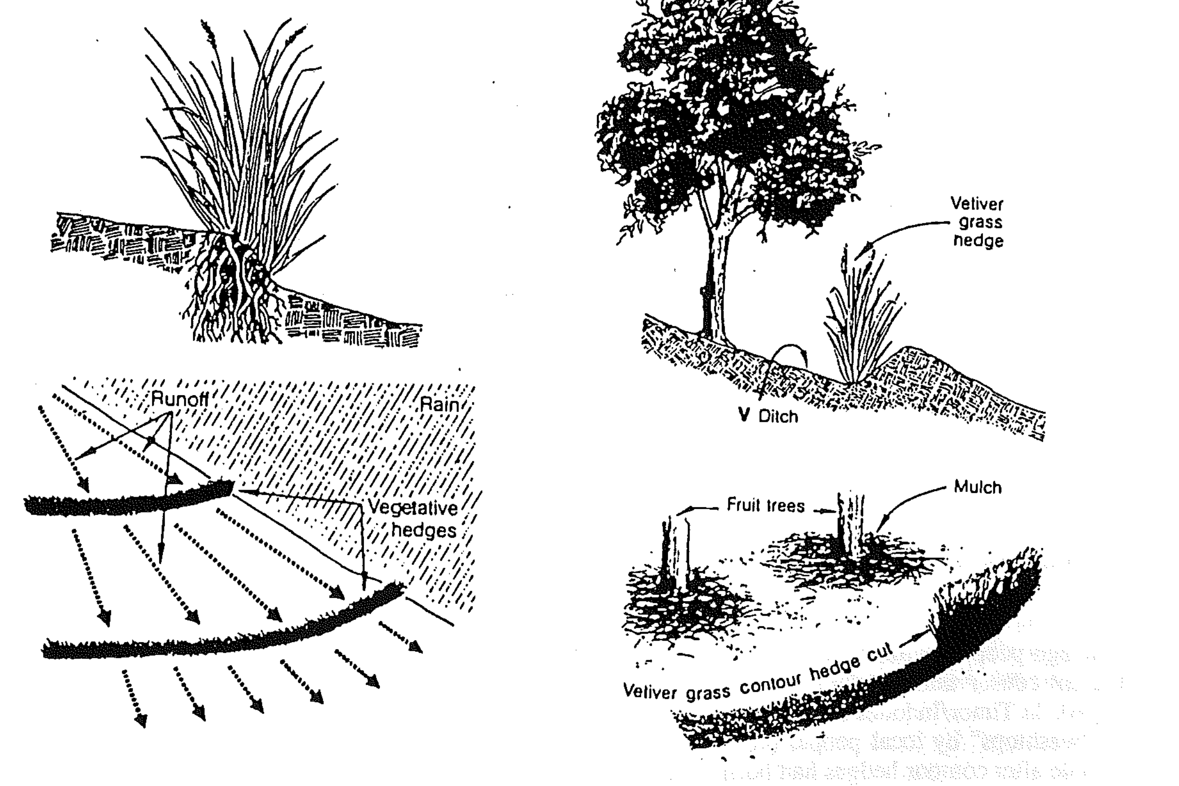


Figure 27: Vetiver grass hedge based soil and moisture conservation in situ (151a)

The vegetative method of soil and moisture conservation uses nature to protect itself. In this case Vetiver grass is being used. Only a 50 cm strip is taken out of production. The collection of runoff has the effect of doubling or tripling the amount of annual rainfall available to agriculture.

The Vetiver grass-based moisture conservation in-situ system is applicable to rainfed tree crops and other crops as well. Vetiver hedges have been maintained and used extensively for the protection of boundary soils by farmers in the State of Karnataka/India, for over 100 years. They never let the plants form seed heads, but keep the hedges cut short (30-50 cm) so that they can also feed the fresh growth to their cattle. They can control the hedge width at about 50 cm, in these flat areas and it is permanent (151a).

3.8.5 Species for combatting soil erosion

Species selection

For erosion control a certain part of the land is taken out of cultivation. The hedgerow candidate should contribute very quickly to the overall productivity of the land. In Thailand laclice were raised on *Cajanus cajan* used to stabilize bench terraces. This is a good incentive to compensate for the land lost and more time involved in ploughing.

Common tree qualities sought for erosion control are:

- fast and healthy growth under adverse conditions,
- vigorous root system with soil-binding properties,
- vigorous vegetative reproduction or direct seeding,
- roots with high strength value in areas prone to landslides.

Multipurpose species which are compatible with cropping and/or plant association have to be considered. Barrier reinforcers (fillers, entanglers) are important as well. Particular attention should be given to the vegetation layers near the ground surface. Fodder plants such as guinea napier or elephant grass, or any perennial green may be found attractive by farmers.

Well known species

Trees and shraubs which have been used in the humid tropics include *Casuarina equisetifolia, Erythrinia spp. Flemingia macrophylla, Gliricidia sepium, Leucaena leucocephala*; in the semi and semi arid regions *Acacia spp., Acacia senegal, Agave spp., Anacardium occidentale, Azadirachta indica, Cajanus cajan, Cassia spp., Combretum micranthum, Euphorbia balsamifera, Ziziphus spp.*in the tropical highlands *Erythrina spp., Opuntia spp., Tephrosia spp.* (for more see Tables 51 and 55).

To create a dense structure and/or fill gaps at the base of the hedges various climbing plants like *Vigna aconitifolia, Dolichos lablab* (28), or fodder plants (elephant, napier) can be used (compare also additional plants for security hedges in Table 10). *Vetiveria zizanioides* is one of the most useful grass hedges used in the all tropical zones.

3.8.6 Examples of occurrence

A long time ago people realized the attractive potential of hedges for combatting erosion. They have been used as an efficient conservation tool in the Andes, where induced terraces with or without wall support can be observed (34). In Timor/Indonesia contour hedges (*Leucaena spp.*) are combined with fallow cover crops which are called "washtops" by local people (40). The cultivation of hills on Flores/Indonesia and Cebu/Philippines was affordable after contour hedges had been established (133).

SALT: SALT is a simple application of a low-cost but effective way of farming hills without losing much top soils to erosion. The experience of an agency in the Philippines with hedges in a search of solution to mountain soil erosion demonstrates an efficient learning process. This organisation tried many ways to stop erosion and restore soil fertility. Terraces were washed out. In the struggle to hold up their terraces it became evident that this could best be done with living trees. *Leucaena spp.* was chosen because it was the most prominent species at that time. After years of experimenting it was found that two dense rows are more reliable than one and that to minimize the risk of pest attack like psyllids a combination of species is a must. Today *Calliandra callothyrsus, Flemingia macrophylla, Gliricidia sepium, Leucaena diversifolia, and Sesbania spp.* are used.

Between the hedge strips permanent crops are planted in one strip out of every four (bananas, citrus, coffee). The uncultivated strips collect the soil eroded from higher cultivated strips. Short and medium-term income-producing crops are planted between the strips of permanent crops as a source of food and regular income while waiting for the permanent crops to bear fruit. Once a month the growing hedge is cut down to a height of one meter above the ground. Cut leaves and twigs are always piled at the base of the crops. In this way only a minimal amount of commercial fertilizer - if any - is necessary. The non-permanent crops are always rotated to maintain productivity, fertility, and good soil formation. To enrich the soil and control erosion effectively, stalks, twigs, branches, rocks, and stones are piled at the base of the thick rows of hedges. It replaces an ugly eroded hill with a terraced and green landscape. Most important of all, the technology can increase the annual income of a financially hard-pressed farmer to almost threefold after a period of only five years.

Woven fences: In arid watersheds in Mexico, woven living fencerows proved to be an efficient tool for protecting fields from erosion by river flooding, as well as trapping the sediments from such floods. With these hedges it was possible to extend farming land and maintain soil fertility (see case study 3, Appendix 1).

3.8.7 How efficiently do hedges control soil erosion?

In Colombia, a study showed that *Gliricidia sepium* contour hedgerows can reduce the soil losses in hill farming by more than 50 %, depending on slope gradient (see Table 19). In the Philippines experimental plots with *Leucaena leucocephala* contour hedges and maize had a very low surface run-off and soil loss compared with bare soil and maize cultivation (see Table 20). Another study demonstrated that hedgerow intercropping with mulch reduces soil erosion by 60 %; 48 % can be attributed to the land covered by hedges, the alleys in between, and the mulching effect. The remaining 12.2 % is related to the changed profile caused by deposits (7.75 %) and contour working (4.43 %) (see Table 21). Another study confirmed this trend; plots with hedgerows had 63 times less soil loss in areas where surface soil was thick and 3 times less in the area where surface soil was thin (154).

Lessons learned from the above studies are that the impact of contour hedges is to reduce soil losses by between 50-60 %, depending on slopes, biophysical conditions and management applied. Careful adjustment of management practices to physical conditions is necessary, e.g. on slopes with a low infiltration capacity. The great volume of surface run-off may break through the hedges and wash away the ridges (226).

3.8.8 Combination with other conservation measures

Living terraces made of contour hedges are effective means of conserving soils on slopes; hedges as a conservation tool must be tied in with other farming and conservation techniques. They can reinforce conservation practices like contour cropping and ditches, which improve the infiltration capacity of the soil. On steep and shallow slopes complementary physical methods are recommended (see also Haiti example, Figure 26).

3.8.9 Problems that may occur when using hedges for erosion control

Preservation of the soil is seldom a primary goal of farmers; especially if the tangible result is only marginally or occurs late. Insecure land tenure inhibits conservation. Aid programs, e.g. food-for-work for hedge establishment should not conflict with the agricultural calendar. Planting of species which can be propagated in dry seasons is one solution.

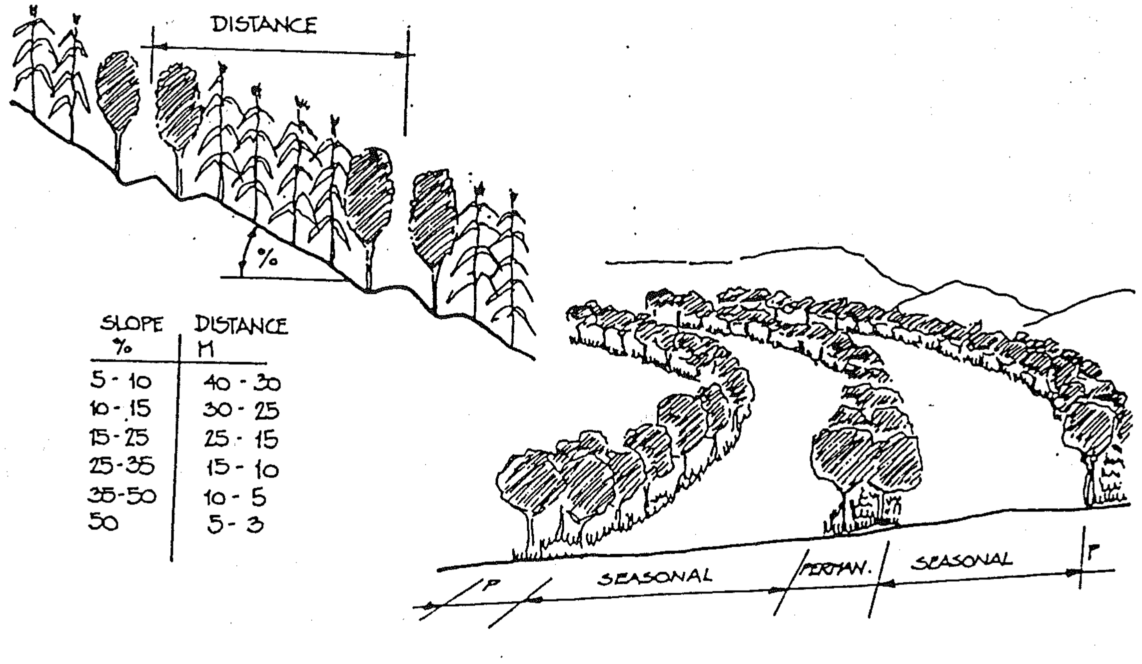


Figure 28: Recommendations for layout and spacing of permanent living terraces - example from Haiti (semi humid) (406)

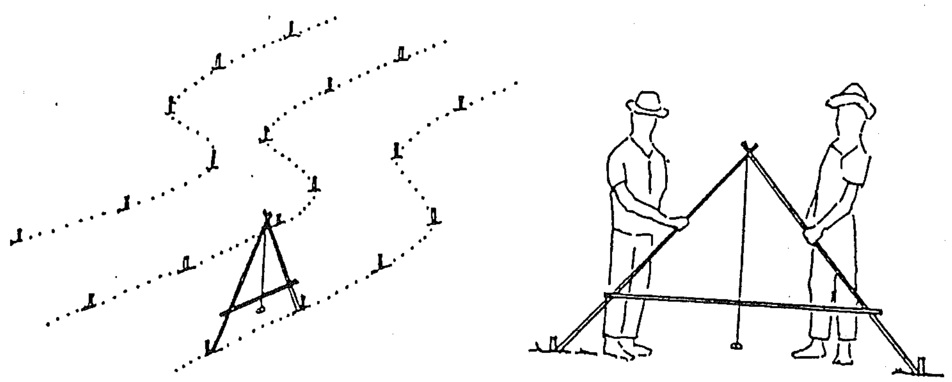


Figure 29: Setting out contour lines with a simple A-frame (406)

Table 19: Comparison of soil losses between alley cropping and conventional farming on hill slopes in Uraba/Colombia (ha/yr)

slope gradient:	45 %	75 %
bare	344.0	282.0
maize	37.6	23.5
hedgerow intercropping*	13.5	13.0

* Maize and Gliricidia contour lines

Source: 430

Table 20: Comparison of run-off and soil losses in hedgerow intercropping and conventional hill farming in Cebu/Philippines

treatment	run-off mm*	soil loss f/plot*	run-off mm**	soil loss g/Plot**
bare	87	3,156	56	5,667
corn alone, stubble removed	30	680	33	2,214
corn/Leuca, stubble retained	2	14	13	712
corn/Leuca, stubble removed	4	88	16	820

*) during 7 months at Dapdad Carcar, total rainfall 1114 mm

**) during 6 months in Patupat, Barilit

Source: Pacardo/Montecillo (96) quoted after (154)

Table 21: Soil losses in hedgerow intercropping systems (153)

USLE factor	cropping system Conventional	Alley cropping
LS	17.3476	15.8313
C	0.4846	0.2222
P	1.0000	0.9500
LSCP	8.4066	3.3418

friable red brown graded soil formation on basalt;
slope gradient 23.6 %, alley width of 4.5 m (hedgestrip 1.5 m).

3.9 Hedges for microclimate modification

Small-scale farmers are relatively inflexible towards climatic conditions. To a certain degree the microclimate can be manipulated and managed. Under the heading micro-climate modification the great relevance for small farmers of manipulating the microclimate will be shown. How hedges can influence the microclimate (solar radiation, temperature, precipitation, dew, evaporation) is outlined. Frost has been identified as one principal problem in hill farming in high mountain valleys. How hedges can be used in frost protection will be shown in detail as well. Wind protection will be dealt with in Chapter 3.10; for the microclimatic impact of mulch consult Chapter 3.7.

3.9.1 How hedges can influence the microclimate

Microclimate manipulation basically makes deliberate changes in the different flows of energy (radiation, heat, and kinetic energy of bulk movements) with the consequence of an impact on the environment of man, plants and animals. This intervention can only be done on a relatively small scale. Priority with regard to climate is to mitigate extreme calamities like drought, cold winds, hail, and storms. These nuisances endanger all production systems but the possibilities of protection are different in higher level input farming (greenhouse, irrigation, etc.). Farmers have experimented with various techniques including mulching, wind protection and surface modification, e.g. ridging. Multi-storey cropping combines various aspects. Hedges are only one option (343).

Microclimate effects can occur as a result of hedges and their products such as mulch. Ecological interactions of hedges refer to effects such as shading, wind protection, and soil (moisture) conservation. The following notes give a brief overview of the potential impact of hedges on

- solar radiation,
- temperature,
- precipitation,
- dew,
- evaporation.

Solar radiation: Solar radiation is modified by the shadow created by hedges. The loss of incoming radiation depends on the orientation of the barrier as well as on the season, but is restricted to the immediate vicinity of the trees. Measurement has shown global radiation to account for about 95 % of the undisturbed radiation at a height above the barrier (86). It is evident that shading is a more serious problem in the early growth stage than later on, and on the west side of the crops (189). However some plants need shade, e.g. Cocoa (*Theobroma spp.*) or are partially shade tolerant.

Temperature: The temperature depends on various factors, such as radiation, soil properties, vegetation, heat conductivity, ground humidity, evaporation, air humidity, and wind. It is very difficult to attribute effects to changes in the temperature pattern near hedges (86). As a rule, windbreaks even out extremes of temperature, raising the lowest and lowering the highest temperatures, while providing better growing conditions for vegetation (136). Under windy conditions, soil and air temperatures are generally higher in the sheltered sites during the day and lower in the night time (86, 89) (for specific information on frost see 3.9.4).

Precipitation: Liquid (e.g. rain) and solid precipitation (e.g. dust) can be distinguished. The overall amount of atmospheric precipitation over a large area is not altered by hedges, but aerodynamic and microclimatic effects can change its distribution. Lower air speed near shelterbelts improves the water balance; light raindrops will drop preferably in the zone of minimum wind velocity around the barrier; heavy rains will not be modified significantly (86). Depending on the quantity of rainfall, the size of droplets and wind velocity, interception by the woody perennial canopy will modify the water balance within the windbreak's area of influence. As any light particles suspended in the air will tend to be deposited in the zone of minimum windspeed, sand will accumulate on the leeward side of the windbreak. In many regions, this effect is used for protection of roads against sand-drifts (see under 3.10).

Dew: Since windspeed is reduced by hedges, air humidity can be higher, and as the radiation balance is changed, modification of the dewfall can be expected (105). Measurements have shown considerable increases (up to 300 %) in dewfall in the lee of the windbreak at a distance of 2-3 times of the barrier height, when winds were moderate.

Evaporation: There is a close relationship between evaporation and wind. The reduction in evaporation is often considered to be one of the most important effects of hedges. Evaporation is slightly affected when wind speed is low and soil is dry (86). Decreased evaporation conserves moisture in the soil. Windbreaks can significantly reduce evaporation and improve the efficiency of water usage (240).

Depending on species and design, hedges can have a favourable impact on enhancing microclimate, e.g. reduction of wind velocity, and thus evaporation. Increasing the night temperature and/or reducing extreme fluctuations in temperature could be very important in forest areas. Translated into economic terms the ecological impact of hedges can result in:

- increase in agricultural and livestock productivity,
- reduction in heating/cooling costs by better protection of buildings.

Hence for small-scale farmers hedges can be an effective means of reducing the adverse effect of climate at the field level, thus making farming more secure.

3.9.2 What research and development activities exist?

Research: Studies on microclimate management are generally confined to windbreaks; some have been conducted on the impact of mulch. A review of traditional techniques (396) went almost unnoticed. A global review and case study on vernacular management by farmers with regard to microclimate in the tropics has recently been completed (344). The application of meteorology to agroforestry has so far not been the subject of more systematic study (first workshop recently, 85).

Development projects: The role of hedges is increasingly appreciated. Their potential role in microclimate management is not yet sufficiently emphasised by research and development organisations. Mechanical understanding like wind protection is reflected in one dimensional approaches, e.g. using hedges for wind protection only.

Nevertheless some projects see in hedges an effective way of modifying the microclimate, e.g. on Cape Verde after large scale reforestation failed it was realised that hedges made dryland farming more secure or even allowed it to expand (152).

3.9.3 What species for frost protection

Following trees have been recommended for the Sierra of Peru: *Alnus jorullensisjorullensis, Buddleja coriacea, Buddleja incana, Cassia hoockeriana, Cassia tomentosa, Escallonia resinosa, Hesperomeles lanuginosa, Polylepis spp., Populus nigra, Verbesina tomentosa.*

Shrubs suitable for frost protection in the Andes include: *Ambrosia arborescens, Baccharis pentlandii, Baccharis salicifolia, Baccharis tricuneata, Berberis lutea, Cantua buxifolia, Cestrum auriculatum, Cleome glandulosa, Dodonaea viscosa, Gynoxys jelskii, Gynoxys macfrancisci, Nicotiana tabacum, Solanum nitidum.*

Frost - one principal problem in mountain valleys

Frost has been identified as one principal problem in mountain valleys, e.g. Peruvian Andes. Farmers are losing up to 80 % of their crops, due to the impact of frost (34). Frost protection may be essential for more secure yields from frost-sensitive crops.

Hedges and frost protection

Only those kinds of frost which occur as an effect of the night radiation of the land are microclimatic phenomena, allowing direct human intervention. Hedges expose the cold air which descends downhill to two essential impacts: radiation and mechanical effects. The irradiation of the hedges within the zone of their influence can increase the temperature. by 1-2°C compared with an open field without hedges. This difference can be decisive in preventing the crops from being affected by the forst. On the other hand a dense hedge forms a mechanical barrier preventing the cold air from descending downhill. At night hedges offer protection from irradiation which can increase the danger of frost. Therefore there has to be a way that the cold air can flow away from the fields (44). In the Central Sierra of Peru (including communities above 4000 meters) peasants also cultivate vegetables and herbs which are protected by circular or rectangular parcels planted with trees (particularly *Polylepis spp.*). Humidity is conserved and the temperature increased (up to 4°C) compared with open field. This is sufficient for the vegetables not to be affected by frost (34).

Principles in frost protection

It is important to know which zones are mostly affected by frost. In this context it is important to know the altitude up to which the phenomenon of thermal inversion exists. This is a precondition for determining the line up to which frost- resistant plants can be cultivated and above this line less frost-resistant ones. Microclimatic studies or local know-how (as existing e.g. among farmers in the Peruvian Sierra) can identify the altitude up to which this phenomenon of thermal inversion exists.

The recognition of this effect has the following design implications: ideally a vegetation barrier should be established diagonally to the slope starting from the upper part and running down to a waterway (river, irrigation ditch, etc.). This "off-contour line" barrier forces the cold air to descend to the waterway which will act as a collector of cold air. With this technique the cold air is not allowed to enter the cropping area (34).

The density of a hedge which is impermeable to cold air can be achieved by natural hedges (multistorey structure and species with dense foliage). In a situation where there is very limited space available a hedge has to be trimmed in a style that increases its density. The density can also be increased by planting the hedge on a ridge (e.g. 1.5 m high can increase the plant density between 10-20 %) (211).

The hedges have to be uninterrupted in order not to jeopardize the frost protection effect. An interruption of around 5 m or more not only means that the protection effect of the break is lost, but even worse, that the effect of the frost is accentuated (34)

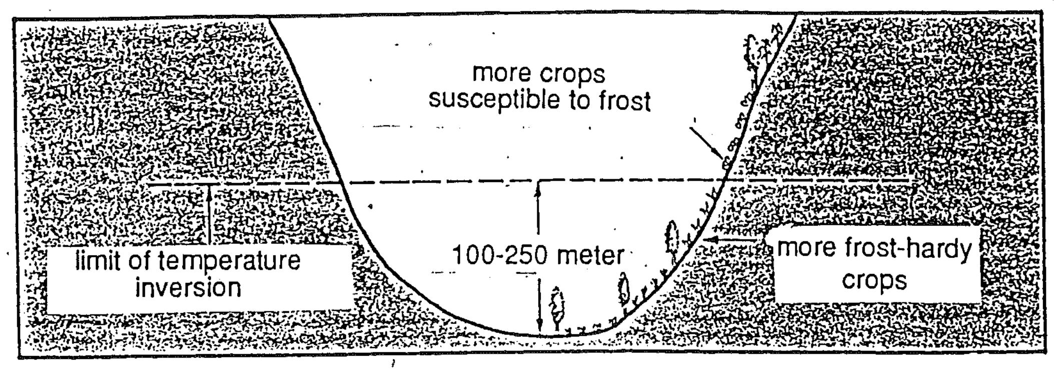


Figure 30: Effect of temperature inversion (34)

The colder air accumulates up to a certain altitude at the bottom of the valley. Above this imaginary line, the air is warmer. Hedges planted in the upper part of the slope can be an ideal defense against this type of frost.

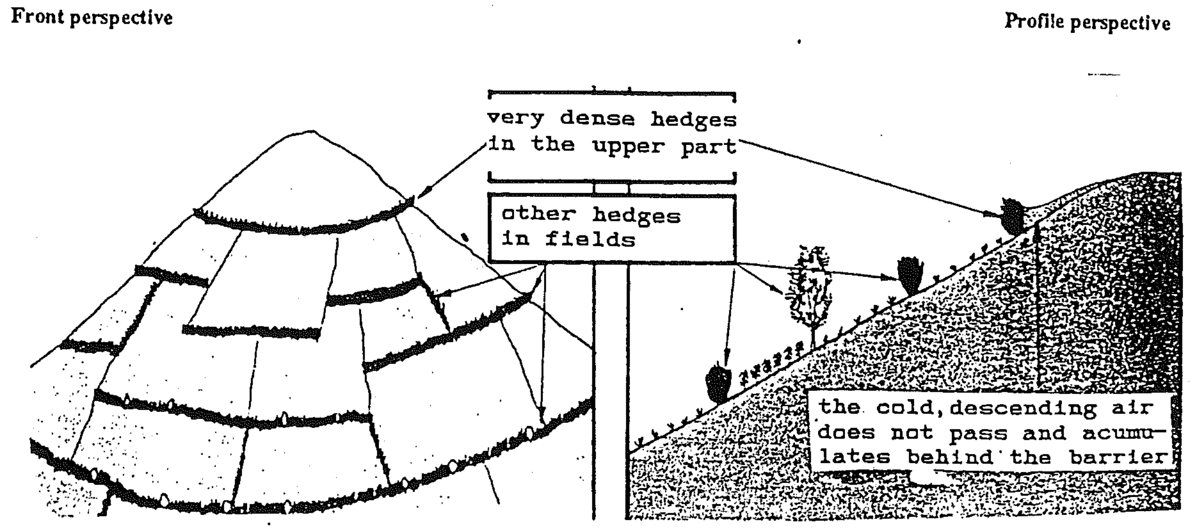
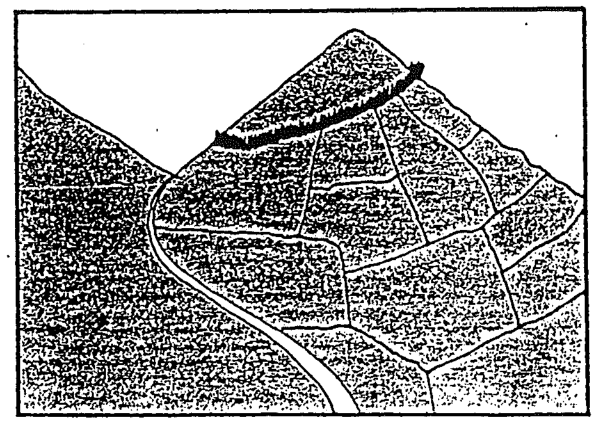


Figure 31: Hedges for frost protection on slopes (34)

slightly modified from (34)



The ideal solution would be to establish a vegetative barrier diagonal to the slope, starting from the upper part down to a waterway. The purpose of the bdiagonal barrier is to shift the cold air outside the field zone.

Figure 32: Mechanical effect of a diagonal (off-contour) hedge for frost protection (34)

3.10 Hedges for controlling wind erosion

Wind can have an adverse impact on the quality of life. Windstress can also affect agriculture very seriously. Some climatic effects of hedges have already been discussed. This chapter focuses on the specific role of hedges which are complementary to or substitutes for the performance of classic windbreaks. The distinction between farm windbreak hedges and other configuratins is drawn very liberally. The role of hedges in sand-dune stabilisation is also noted. Principles and design guidelines for windbreaks are described.

3.10.1 Some benefits of windbreaks

Purpose and definition

Strong wind can reduce the quality of life. A special need for wind protection exists in more arid areas, especially where soil is loose and sandy; crops sensitive to wind like cereals are grown; hot dry wind causes high consumption of water by irrigated crops (88, 381). The need for shelter is important for livestock as well.

The need for land-use intensification may result in deliberately converting these strips of vegetation into narrow multipurpose and productive hedge-like bands; modern treeless farming depends on costly artificial or planted windbreaks.

Barriers of vegetation serving primarily to break the force of winds and to provide shelter are generally called windbreaks. Often the term shelterbelt is used synonymously; it refers to windbreaks consisting of more than a few rows (381).

Foresters use the terms shelterbelt and windbreak interchangeably. A useful distinction can be made between multirows of trees extending for several kilometers - shelterbelts, and shorter, single row boundary planting - windbreaks. A more important difference is that between public and private planting (9). These conventional windbreaks, both either farmborder windbreaks and classical shelterbelts (many rows wide), have in common the long "gestation" period till the ecological effect of protection occurs. The main difference is that classic shelterbelts require uniform land tenure.

The primary purpose of windbreaks is to reduce the velocity of the wind immediately above the ground in order to protect crops and pasture, buildings and livestock enclosures (126). Windbreak trees and shrubs, if properly maintained and harvested, can also provide significant qualities of fuel and poles without jeopardizing their primary function (381).

Benefits of windbreaks include:

- Prevention of further erosion, and thus of loss of soil fertility in the sheltered areas;
- Increase in average crop yield owing to reduced wind velocity;
- Increased crop residues and more dry-season fodder for livestock as a consequence of higher yields;
- Value of other tree products (fuel, poles, fruits, etc.) (9)

Crop yield depending on the kind of windbreak

Naturally, a farmer asks how much a windbreak can help to increase the yield, the quality of the crops and animal products. The answer is not straightforward, but site-specific. Windbreaks have repeatedly shown a favourable influence on crop yields by providing protection against wind and water loss. In China, for example, windbreaks reduced wind velocity by 28-32 %, increased air humidity by 6-123 %, reduced evaporation by 15-20 %, and increased soil moisture by 15-25 %. Crop yields have been increased by 16 % for maize, 36 % for soybeans, 43 % for sorghum and 44 % for millet in fields protected by windbreaks (398). An increase in yield of nearly 300 % has been observed (8); for illustration of impact on economic yield see Fig. 33).

Table 22: Land use in drier regions with no wind protection, with shelterbelts or hedge windbreaks compared

Items	No protection	Shelterbelt	Hedges
Definition	no windbreak	multirow,sever.km	one row
Implementation	private	public	private/local
Area occupied by trees	zero	around 12 %	10-20%
Rise in gross farm income due to ecological effects	decline	15-25 %	5-25 %
Ecological effect appears	never	>7-10 years	>1-2 years
Decline in soil fertility ceases	indefinite	>8 years	>1-2 years
Tree products	none	significant	significant

The common assumption of 20 % net increase in yields (after allowing for the area, moisture, and nutrients taken up by the trees themselves) has been verified by numerous field measurements in various countries over the last sixty years (for summary see 124, 204a).

In semi-arid areas the effect can be higher. In dry years the effect on yield may be much greater than 20 % because the marginal benefit of the added soil moisture is greater. For example, whereas crop yields may fall by half or more in unsheltered areas in dry years, sheltered areas may experience only moderate decline (8). A greater effect is to be expected in years with less rainfall, because the incremental benefit of additional nutrients and moisture is likely to be greater under these conditions.

On degraded or marginal sites the incremental impact is far less, e.g. for example a 20 % enhancement of yield when soil fertility has already been degraded. However what other choice do resource-poor farmers have if they are to continue cultivating their marginal sites? Given the above evidence it seems reasonable to expect a 15-25 % increase in crop yields in windbreak areas as the trees approach mature height. In arid areas the positive ecological results of conventional windbreaks do not set in until after 8 years. For small-scale farmers and quickly degrading soils this may be too long. The precondition is a technically sound windbreak. It is assumed that jetting can be reduced by planting shrubs and hedgerows which may increase the effect on yield by 5 % (8) or much more. Windbreaks with a bare base can even be negative (116) (see under general principles: homogeneity).

Whether a windbreak hedge has a positive effect depends entirely on local conditions, e.g. low wind speed is usually more advantageous for water-balance of the soil, but not in wet areas and not when ripe but still moist crops must await harvest time. In these cases, an increase in evaporation would be desirable (343).

Sometimes it is suggested (e.g. 88) to confine windbreaks in arid zones to the protection of irrigated land. However, for poor farmers and poor regions hedges can be an important microclimate manipulation, too. To the farmer the problem of wind protection is first and foremost economic. When windbreaks help vegetables or fruit to ripen quickly so that the farmer can be the first to get them to the market or if the quality of the product (e.g tobacco) is enhanced by shelter, he/she will be motivated to grow windbreaks (116).

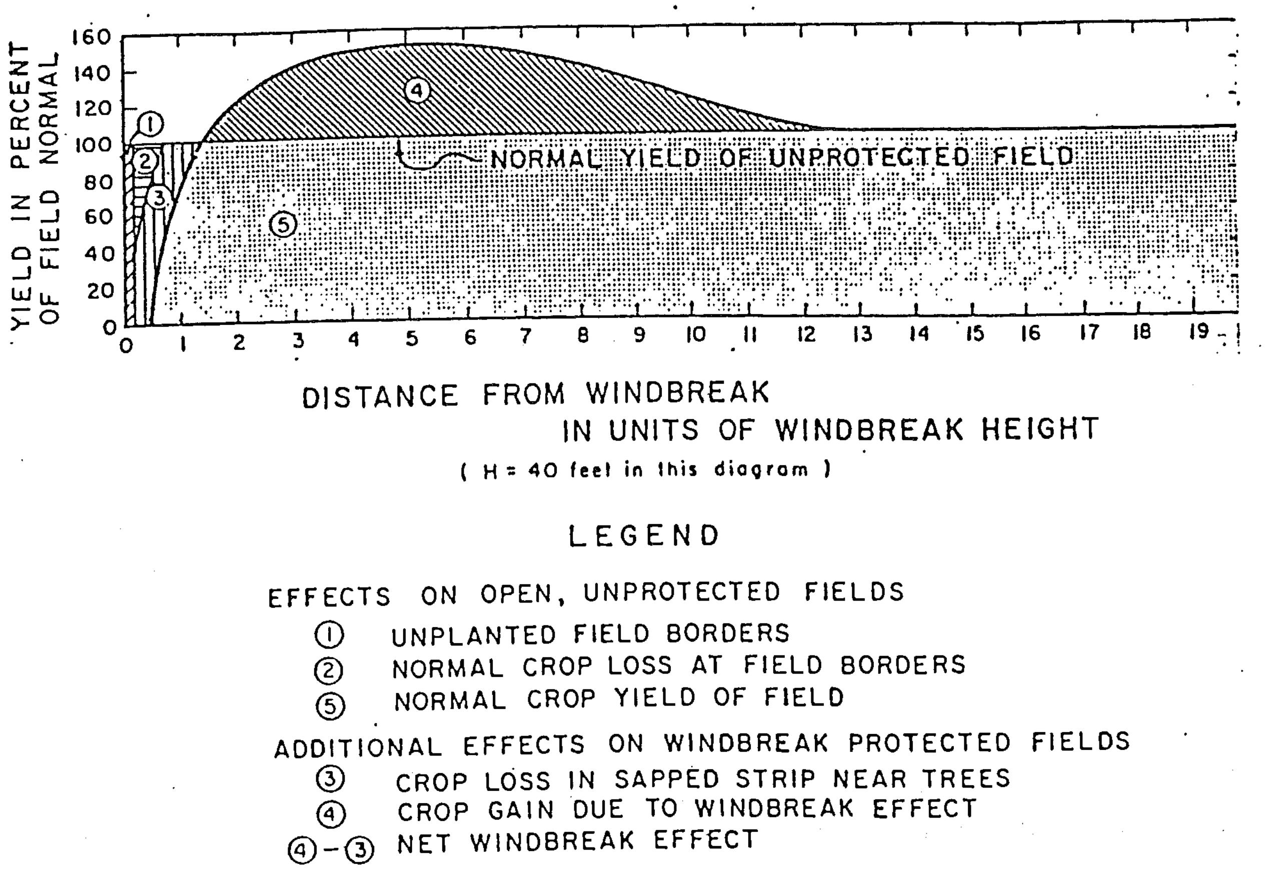


Figure 33: Impact of windbreaks on economic yield (34a)

Livestock

The impact of windbreaks on animal production can include

- longer pasture period,
- less water consumption,
- weight increase,
- higher reproduction rate, and
- reduction of energy required to maintain body temperature (116, 210).

In harsh climates wind not only reduces animal productivity, but even causes death of the livestock (366). The absence of shade requires more energy for respiration and increases loss of body water (210).

Crop residues and fodder from windbreaks provide dry season fodder for livestock. The amount of stover (cured stalks) available rises linearly with crop yields, e.g. a 20 % increase in yield in traditional agricultural crops like sorghum produces approximately 350 additional kg of stover per hectare. With modest use of fodder from hedges this figure can rise to more than 500 kg/ha, easily sufficient to support an additional 50 kg goat. A ton of sorghum or millet grain may be associated with up to two/three tons of stover (and thus a 20 % increase in grain yields can produce half a ton of stover) supplemented by planting fodder trees and shrubs. This is sufficient to support slightly less than one cow per hectare during the dry season (a cow equals one tropical livestock unit - TLU of 250 kg) or four 50 kg goats (8).

3.10.2 Specific potential of hedges

Since the width of the windbreak is of little importance, single (or double) rows of tall trees and shrubs are sufficient protection against wind. Hedges are also very suitable for underplanting tall trees with an open base. A sparse or open base gives no protection to people, livestock and crops (34, 189). Worse, it can have a negative impact. A study which measured the velocity of the wind in the stem storey of a row of avenue trees found that it was equivalent to 115 % of the velocity of the wind in the open. Under this kind of planting under rows of poplars, for instance - some lower woody species should be planted so as to close the stem storey and to meet the demands of a really good windbreak (116). Indeed, this is a prominent place where conventional windbreaks need support from a hedge component. Owing to their height hedges do not cast much shade around farmland and orchards; a network of hedges is as efficient as taller windbreaks. Small garden hedges in closer spacing are the only viable option in small gardens owing to their size.

3.10.3 What research and development activities exist?

Research: An appreciable amount of research has been carried out on classic windbreaks in temperate and more arid regions. Little information exists for more humid areas (119) (e.g. 133). The primary effect of reducing wind speed has been most studied, although the mechanical explanation has been oversimplified.

Various reviews have been made with regard to classical windbreaks (e.g. 119). Attention to techniques of traditional wind protection in the tropics is of very recent date (343). Hardly any research results exist even on the principles of the most common traditional techniques like trees planted around fields. Review exists of small windbreaks (hedges for developing countries). Research has been confined to trees, but the same principles apply to hedges on a smaller scale (343) in most cases. Little information is available on socio-economic issues, apart from microeconomic evaluation of a few classical windbreaks (e.g 119; 8).

Recently ICRAF/University of Wageningen started a collaborative program on meteorological issues in agroforestry with an interest and mandate for windbreak hedges. The University of Hohenheim/FRG, in a collaborative agronomy study at ISC, has started to evaluate the performance of some trees and shrubs (e.g. *Prosopis spp.*) to protect seedings during their early development and their impact on the yield of agricultural crops on sandy blowing soils in West Africa (215a, 368). Some research on hedges has also been conducted in Pakistan (22) and India (294) and by IDF support e.g. in Senegal (143).

Development: Today windbreak hedges are more appreciated in development projects. The potential of hedges is gradually being realised in food-for-work programs and integrated rural development projects,

In India (294),Pakistan (294) and the Sudan (215a), to name only a few, farm windbreak hedges are promoted. *Moringa stenopetala* was suggested as a windscreen in Sudan (5a). The higher awareness of the role of hedges for wind protection is hampered by insufficient hard data. This is one explanation why e.g. advisers for food-for-work programs find it difficult to establish work norms (workdays per food for work) and may in the end decide not to include a hedgerow component in a food-for-work program.

3.10.4 Occurrence and windbreak species

Species selection

Some of the qualities required for trees and shrubs used as windbreaks are:

- Bushy shrubs or low branching trees with dense evergreen foliage; bushy and deep crowns have to allow some wind penetration, no shedding of lower limbs,
- wind firmness of roots,
- rapid growth if early protection required,
- a minimum height,

- tolerance to harsh environment and capable of withstanding strong winds (hot or cold); or the effect of salt-laden winds in coastal areas or wind-born sand in desert areas,
- long life, and
- pest and disease resistance;
- do not harbour pests detrimental to neighbouring crops.

Indigenous plants have been proved to be very appropriate for windbreaks (304). Unfortunately some of them grow very slowly. A combination of fast-growing exotics and hardy local ones is often appropriate.

Plants grown almost exclusively for wind protection should not be in competition with agriculture on limited resources (water, nutrients, etc.). Trees consume more water than other plants. Species which do not contribute to overall productivity should not be considered. A deep taproot takes almost nothing away from these crop plants, but such a root system is obviously ineffective for dune fixation. It is important to know the time of the year at which protection is most needed. For year-round wind protection only evergreen species can be used. If there is only a need for protection during the rainy season several alternatives have to be considered, e.g. relying on annual crops like maize, sorghum or temporary hedges.

Quick-growing trees like some *Eucalyptus spp.* may leave several meters unprotected above the surface, if stems are not underplanted with smaller plants (34), e.g. extensive windbreaks *of Eucalyptus caldocalis* in Australia and *Eucalyptus diversifolia* in South Africa failed due to shedding of the limbs (38). Nearly impermeable species like Cyprus are not very suitable either. There are many options in mixing species; however, to obtain a homogeneous structure, especially in one-row windbreaks, the mixture should be simple (73a, 165). An appropriate physical structure can be obtained from alternate species or rows of trees and shrubs or 2-3 shrubs between the main tree species (153b). Fast-growing with slow-growing species (long and short living) are recommended as well (381), e.g. *Cedrus deodara*, as the denser, slower-growing tree to windward, and *Pinus radiata*, as the faster-growing, tall species in the lee (355).

Some species like *Parkinsonia aculeata* and *Tamarix spp.* may be used as main row species under dry farming techniques or as a hedge under irrigation, if other trees have been used in the main row to provide the necessary height for the shelterbelt (73a).

Well-known species

Some species which have proved to be important for wind protection for the humid tropics are *Casuarina equisetifolia, Dichrostachys cinerea, Gmelina arborera, Leucaena leucocephala, Kaya senegalensis;* for the tropical highlands *Acacia decurrens, Erythrina spp., Grevillea robusta, Morus alba, Schinus molle;* for the arid and semi arid regions *Acacia nilotica, Azadirachta indica, Bauhinia rufescens, Cassia spp., Combretum micranthum, Parkinsonia aculeata, Prosopis juliflora, Rhus lancea, Cupressus spp., Tamarix spp., Ziziphus spp.* The most drought-resistant species include *Cupressus spp.* and *Casuarina spp.; Tamarix spp.* is highly salt tolerant (166) (for more species see Tables 51 and 55).

Occurrence and patterns of windbreaks

Windbreaks consisting of trees and shrubs are traditionally well known to provide shelter for crops, animals and human dwellings (general review see 344; for arid zones 119).

In Pakistan *Prosopis spp.* and *Acacia tortilis* farm windbreak hedges are promoted around palm orchards (294) and in India e.g. *Prosopis spp.* is planted around agricultural fields and some research stations (294).

In Latin America heat and moisture modification is an important incentive to plant windbreaks due to the absence of natural shelter (and traditional techniques like mixed cropping). Windbreaks have been established in cashcropping regions to protect nurseries of tobacco and coffee seedlings, citrus orchards, and for tea plantations in East Africa (344).

Temporary windbreaks, e.g. consisting of closely planted maize (*Zea mays*) rows, may be sufficient if the wind protection is only in the cultivation season for annual crops. This technique has been observed among the Mayas in Yucatan (261), for example. Sometimes Sorghum is used for temporary protection (215a). *Saccharum spontaneum* provides a dense windbreak hedge (304).

Regions can be protected against wind by successive windbreaks or network systems, including secondary hedgerows (86, 119). An interesting example is the "bocage" system found in Nigeria (97). Hedges and other trees/shrubs are commonly grown on all sides of farming land (for one model see Figure 34). In Tanzania bananas (*Musa spp.*) grown closely together proved to be an excellent traditional shelter (343, 344) (for some designs see Figures 51, 52).

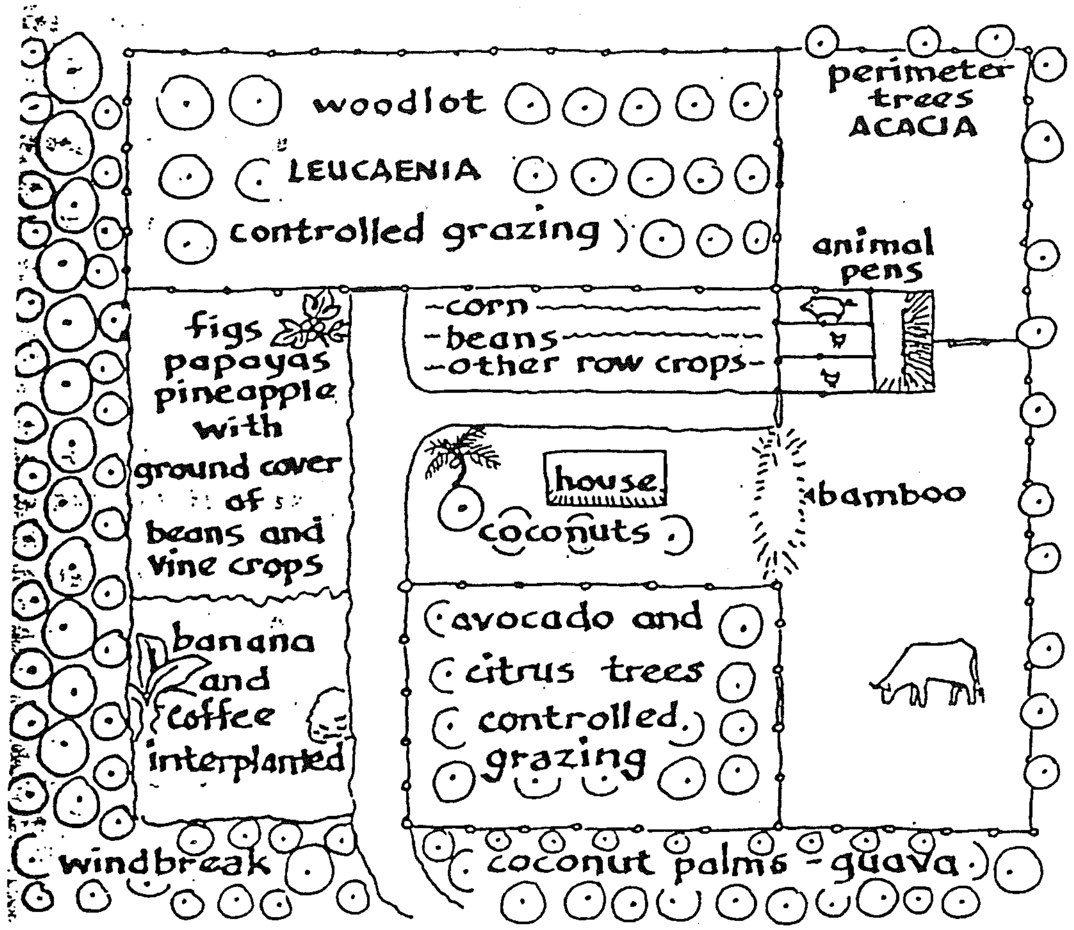


Figure 34: Farm windbreak model for arid climates (126)

The outer rows of the windbreak may consist of coconut palms, guava, and acacia; the inner rows may consist of tamarisk, casuarina, and eucalyptus. Single plant species, particularly those that sprout after cutting (such as eucalyptus), can sometimes be managed to provide full vertical shelter by alternately cutting the outer rows of trees and allowing the cut trees to complete the shelter.

3.10.5 General principles

> *"Planning windscreen systems theoretically is far easier than executing the plans in the field, because even ideal windscreen systems must take into account the size of the field, or fields, to be sheltered and the position of roads, ditches, houses, and other obstacles." (116).*

General principles which have to be considered in planning windbreaks are:

- physical structure: permeability, height, and homogeneity;
- orientation: cardinal points, land tenure;
- regulations: among neighbours and communities.

Table 23: Principles of an ideal hedge windbreak

Permeability:	40 to 60 %
Height:	proportional to the distance to be protected * 10 - 20 times the height of the mature tree
Homogeneity:	well furnished from the base to the top * multi layers of vegetation in one line * multi rows
Minimum length:	12 times height
Width of belt:	does not affect the efficiency of wind protection
Orientation:	perpendicular to prevailing wind direction
Network integration:	supplementary reduction of wind velocity
Species composition:	adapted to climate and soils, produce preferred output(s) * More species for better resistance * Several species in the same row * Several rows with different species * Restricted number of species for easy management
Outputs:	food, fodder, fuel, timber, etc.

modified from (153a)

Physical structure

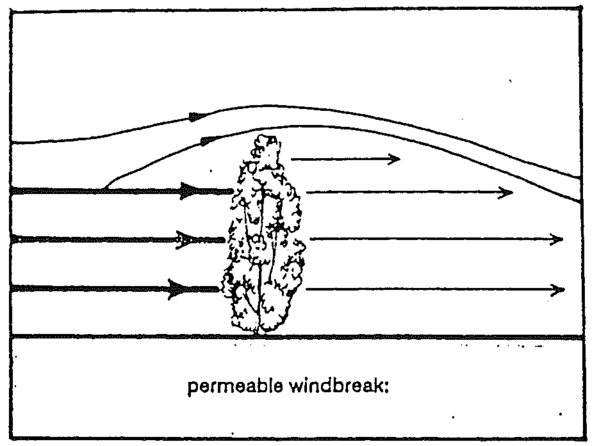
Hedges can act as a break or screen to reduce wind velocity on both sides of the hedge. The amount of reduction depends upon the structure and the permeability.

Permeability: How efficiently the windbreak blocks the wind and confines the wind turbulences to the zone close to the windbreak depends on the permeability of the vegetation (see Figure 35). A vegetation density (vertical growth) of 40-60 % but not greater than 80 % works best (381). A barrier dense enough to completely block wind passage will cause turbulences close to the ground, loosening soil particles that can then be picked up by the wind as well as removing much-needed topsoil. Wind that is carrying soil particles causes damage to crops through the abrasive effect of the sediment load on plant tissues. Compact hedge screens are the most efficient in reducing wind velocity, but only over a limited distance. Permeable hedges provide less absolute reduction in wind speed but affect a greater distance downwind and are more economical for this reason. Clipped hedges may be rather too dense, causing occasional turbulences (44). The best windbreak hedge, as a rule of thumb, is one through which movement can be seen but objects are not clearly distinguishable.

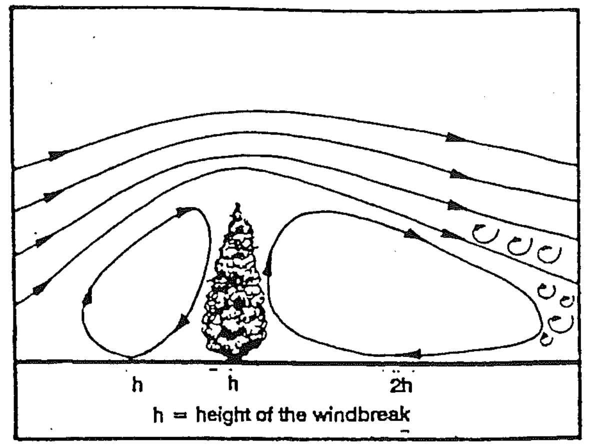
Homogeneity: It is also important that the windbreak is homogeneous in vertical shape, i.e. that shelter is provided down to the ground surface. Certain fast-growing species, while impressive, may eventually leave several meters unprotected above the surface, except by stems. In such cases, the belt must be underplanted with smaller trees and shrubs. To support a homogeneous structure, hedges are very appropriate, because they are - by definition - a continuous line close to the base. However to protect a greater distance downwind, they should be planted in either wider intra-row spacing or thinned out.

Height: The extent of the shelter effect in terms of windspeed reduction (and therefore evaporation) is proportional to the height of the windbreak. Depending on windspeed and permeability, the effect of the windbreak is significantly felt upwind to a distance from five to ten, or even 20 times the height of the tree, but often less. On the leeward or downwind side, however, the area of the protected crops extends for between 10 and 20 times the height of the tree (73a, 381, 119, 189).With increasing mechanization, tall-growing species must often be chosen for the protection of larger plots (116).

Permeability

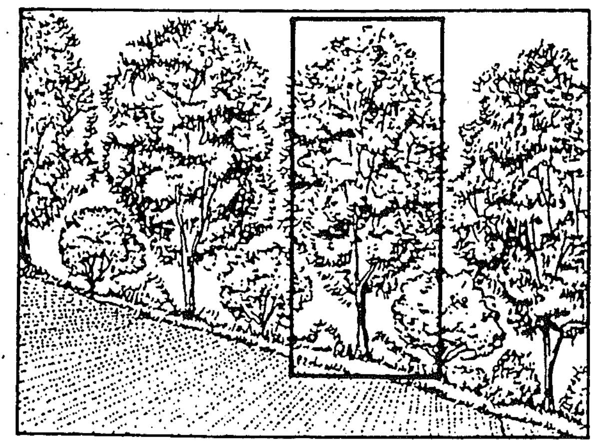


The permeable windbreak reduces the velocity of wind without producing turbulence



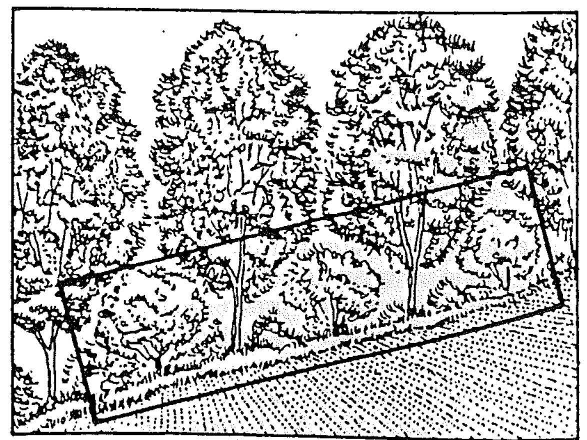
An impermeable windbreak abruptly stops the wind provoking turbulence felt up to a distance equivalent to twice the height of the windbreak

Height



The zone of the protected crops is equivalent to 10-20 times the height of the windbreak, when it is located perpendicular to the direction of prevailing winds

Homogeneity



It is important that the shelter is provided down to the ground surface. An ideal combination consists of trees and shrubs.

Figure 35: Structural principles of windbreak designs (34)

Table 24: Parameter to calculate protected area by a windbreak hedge

The financial benefits attributable to a windbreak hedge on the farm can be calculated theoretically using the following assumed parameters.

H = height of mature tree	a = area of field l x w
L = length of hedge	P = protected area L x 20 H
l = length of field	y = yield/ha of unprotected crops and forage
W = width of hedge	z = yield/ha of protected crops and forage
w = width of field	p = price of outputs
A = area of windbreak L x W	

Assumption:- protected effect of windbreak is 20 times of height of the mature tree
- crop, forage yield increase is e.g. 20 %

Layout and orientation

The layout of windbreaks has to be flexible to fit into the context of existing land uses.

General orientation should be perpendicular to the prevailing wind direction. The length of the barrier is important to maintain a reasonable degree of shelter when the wind varies from a direction normal to the barrier. Whenever wind direction is indeterminate shelter is best provided by a network of barriers. A main tall windbreak and secondary hedges are recommended (189). When wind comes from any direction, all four sides of each field must be hedged for full protection. To shelter significantly an entire field with an e.g. 1.8 m hedge, the field must be in the order of 44 m2 (20 h leeward shelter effect plus 4 h windward shelter effect) or about 0.2 hectare (44).

The angle between hedge and wind is important. Shelter decreases in proportion the more the direction of the wind corresponds to the direction of the long axis of the screen (44). Windbreaks established at equal distances one behind the other have been shown by experience to have a sustainable, more favourable effect than might be expected from single ones (201).

The siting of hedges affects their shelter value. Long parallel hedges may work when the wind is blowing at right angles to them but funnel and increase the speed of parallel winds. In Sicily, temporary shelter screens are placed at right angles to the parallel hedges to prevent this. Gates and gaps in hedges similarly funnel the wind, as can hedge trees, which may make certain parts of a field susceptible to lodging (44).

A network of shelterbelts works best when the windbreaks are planted perpendicular to each other. For livestock, a shelter in U, V, X, or square form can be used. An L-shaped pattern across the prevailing wind direction is advisable around buildings. Windbreaks should not be planted too close to the buildings (126).

Cardinal points: Tall windbreaks (8-15 m) protecting farmland will impose much shading. They should be planted in a north-south direction. Shading is a more serious problem on the west side of the field. Small windbreaks (preferably hedges 3-5 m tall) should be planted in the east-west orientation to minimise permanent shade to the crops situated north of the windbreaks (see Figure 37).

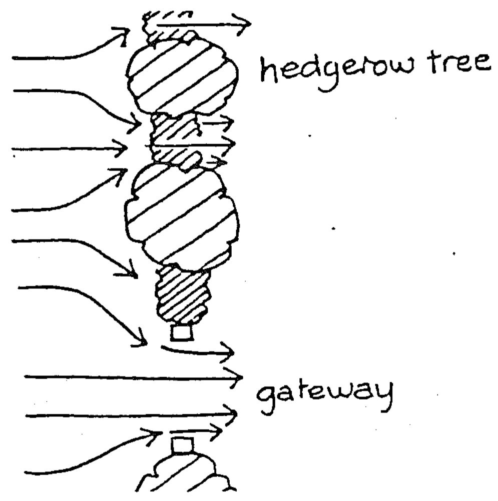


Figure 36: Funnel effect of hedgerow trees and gateways (top view) (44)

Slopes: The question of the orientation of windbreaks becomes more complicated in undulating areas and on slopes, where the design is frequently only locally applicable (44, 57). Contour hedges have to be considered when soil erosion caused by water is the main problem.

A hedge sited along the top of a ridge or on a hillside has its height effect enhanced by the slope of the land behind it. This makes a more effective shelter when the wind is in the right quarter. On a flat-topped ridge, however, the cover is only average. Wind tends to be deflected or funnelled into valleys. Hedges most effectively block these winds when located at right angles to the valley.

The most difficult fields to protect are those which slope into the prevailing wind. Here the hedges' effective height is greatly reduced and on southerly slopes shading is detrimental to crops (44).

Land tenure: In a situation of complex land tenure patterns or when there is no local consensus on windbreak planning, it may not be possible to establish continuous straight rows of trees across individual fields and parcels. In this case windbreaks may be staggered so that they conform with established boundaries such as the borders of fields, roads, streams, etc.

Staggered windbreaks can also provide the most effective protection around towns and villages where they are laid out in a pattern of overlapping blocks (see Figure 42). The advantage of including roads, trails, or driveways for livestock in windbreak lay out is that people and animals can benefit from a shade passageway that otherwise would be very hot. Any path through the windbreak should be at an oblique angle rather than perpendicular to the vegetation rows. This will allow free movement through the windbreak without opening a gap for the wind to roar through (381).

Regulations: The applications of the structural principles do not inhibit flexibility in layout as assumed by classical windbreak designers. Where there is a reluctance to participate in a shelterbelt project at the local level, promotion of individual hedges may be the starting point (around fields, hedgerow intercropping). For farm windbreaks (hedges in general), arrangements must be made between neighbours on planting and the sharing of benefits. It has to be clear before the windbreak reaches its optimum size who is responsible for maintaining its shape and sheltering effect, and who has the tree (or part of the tree) tenure rights.

Beyond farm boundaries coordination and cooperation may be essential, but difficult to achieve to increase the overall benefit of the windbreak project or avoid turbulence. The consensus at the local level is important, because often after the harvest, the animals are usually allowed to browse the crop residues left in the fields. Keeping the animals away from the windbreak during this time is difficult and fencing along narrow strips of land is costly (381). Hence protection of trees is often more difficult than planting.

Windbreak length and width is of minor importance

Width and length are of minor importance in the design of a windbreak. The principal problem in the design of a windbreak is to achieve a maximum protection with a minimum sacrifice of land without impairing the stability of the windbreak.

Length: The hedge must be at least twenty times as long as it is high for the shelter effect to work well. Otherwise wind eddies around ends of the hedge and reaches more of the field behind it. If harmful winds can come from any direction, all sides of a field should be protected (44).

Width: No simple rule exists on how many rows are necessary for good protection against wind. The width is of minor importance; in theory a single row is often sufficient (88). Windbreaks established at equal distances one behind the other have shown by experience to have a sustainable, more favourable effect than might be expected from single wide ones (201).

Single-row windbreaks can be effective and break the wind as efficiently as wider belts. As noted earlier in the example from China, single rows of trees have been found more suitable by farmers than multiple rows, because they occupy the least amount of space, for the amount of protection they offer (116).

In comparison with more rows, single ones allow better development of individual plants (165). Generally, hedges are more affordable and acceptable by small-scale farmers than classic windbreaks. However, the risk of one row is that it may develop and funnel winds. The advantage of more rows represents fewer problems and allows greater flexibility in the long run. The failure of the occasional tree no longer provokes a wind problem. Also harvesting of the plants in alternate rows by coppicing is possible without destroying the shelter. Temporary species can be incorporated for quick growth and subsequently removed, having nursed slow growers, long-lived ones and/or slow plants.

The advantage of combining fast and slow-growing (particularly hardy) species is obvious. The slow-growing plants provide low shelter at the windward side. In this shelter the fast growing species can quickly grow. In some cases it may even be necessary to establish a barrier (stockproof plants, ditches, etc.) to keep out livestock from the windbreak.

As a general rule, shelter does not require more than one or two rows as long as the trees are branched from top to bottom (homogeneity), and so long as none of the trees have dropped out. The narrower a screen is made, however, the more important its proper management becomes. Finally it is the farmer who must decide how many rows of trees he/she will plant for a windbreak (116).

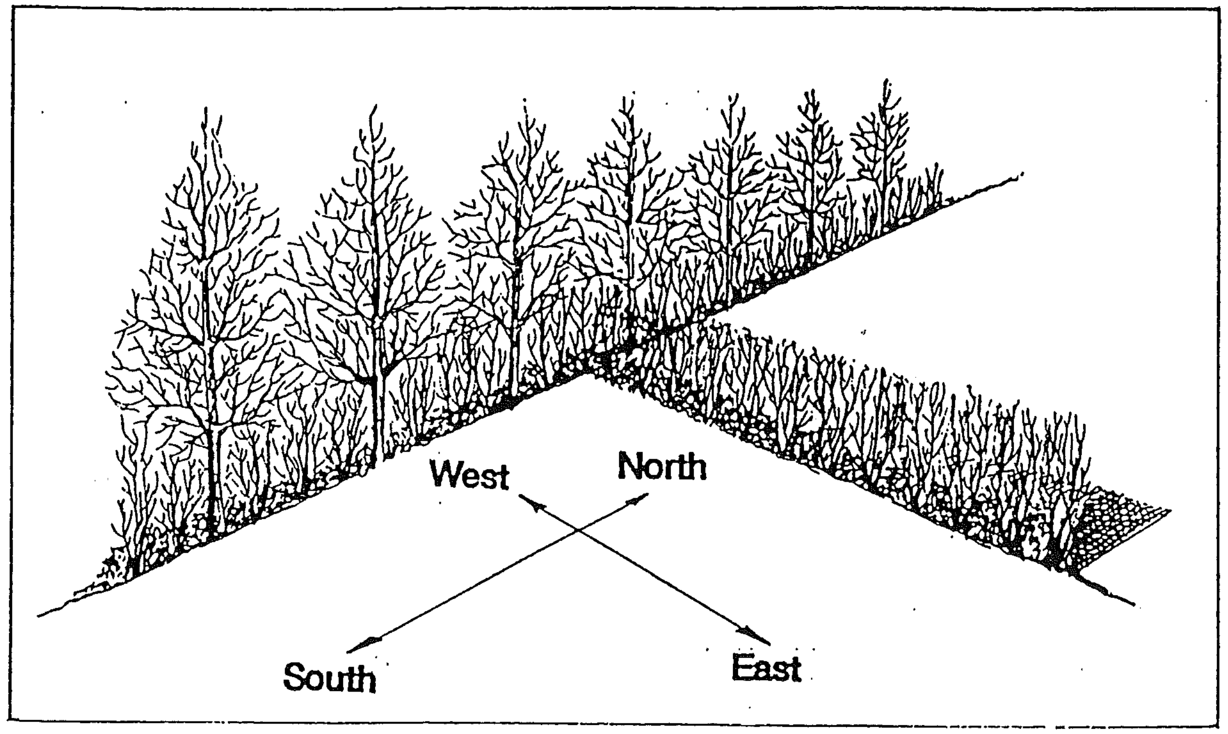


Figure 37: Orientation of a windbreak (189)

The large windbreaks are planted in North-South direction. The windbreaks with a West-East orientation should not be too tall to avoid permanent shade in the field located to the North.

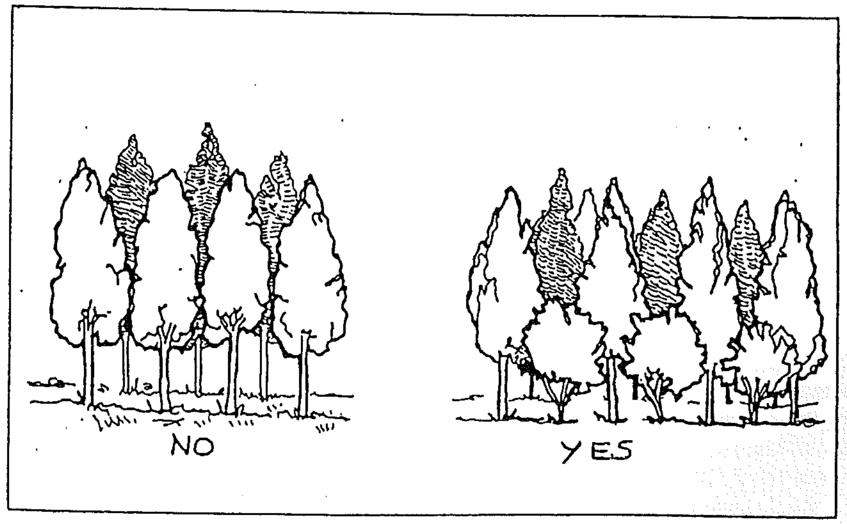


Figure 38: The importance of homogeneity of a windbreak (34)

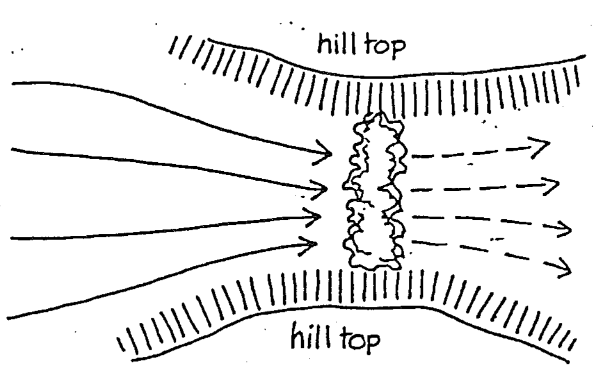


Figure 39: Valley hedges to block wind tunnels (44)

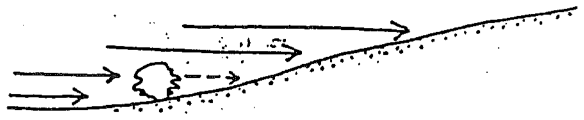


Figure 40: Hedges on slope facing wind (44)

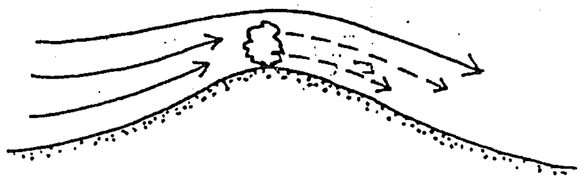


Figure 41: Hedge on hill crest (section) (44)

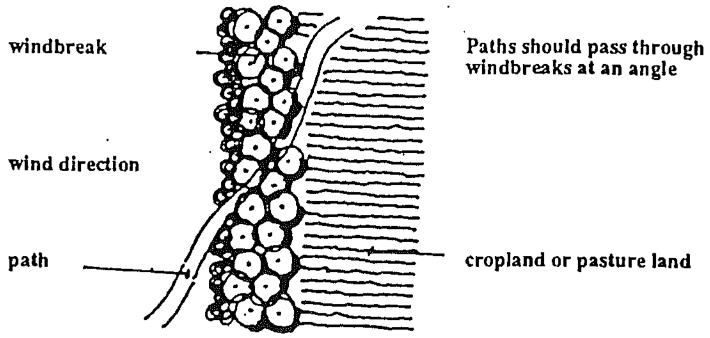


Figure 42: Windbreak layout according to existing land uses (381)

Effect of hedge shape on wind

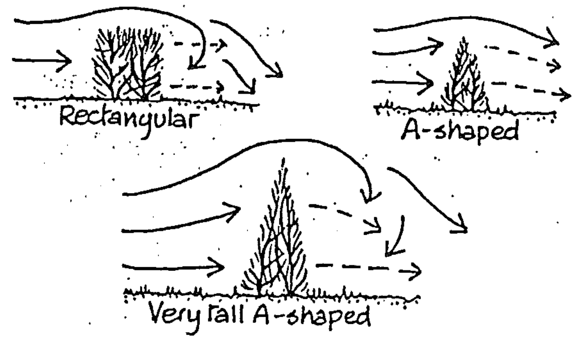


Figure 43: Effects of hedge shape on wind (44)

The A-shape or topped A hedge makes the most effective windbreak, because it allows wind to pass over it with less turbulence than the flat-fronted shape. In arable fields a tall hedge (>1,8 m), if very dense, may be of less value than a lower hedge, because it causes wind turbulence behind the hedge, flattening the grain there (44). When permeability cannot be controlled or a dense hedge is a must (frost, noise protection, stockproof hedge) a compromise must be sought.

3.10.6 When are classical shelterbelts/windbreaks and/or hedges appropriate ?

It is therefore time to draw conclusions about windbreak development and research. A departure from the classic concept is warranted in many cases. For optimising scarce development funds, wide belts following strict lines with costly protection often against people and animals are not justified. This is particularly true if shelterbelts are established by food for work, when people see in them only a temporary source of employment. If not based on commitment of farmers and community, a windbreak project can ultimately result in an investment to protect abandoned fields, because farmers left before the effect could occur.

Development support should focus on the promotion of many small windbreaks, and coordination of local design, where practicable. The spread of scarce development resources to support small land users with little external inputs is required.

Participation: To plan an effective windbreak, one has to know what is supposed to be protected and improved. Understanding the priority of land users and realistic assessment of what is plannable by outsiders can only be achieved by involving the community. What is needed is not primarily to maximize the wind protection; immediate wind protection in degrading areas is warranted. Flexibility in design and commitment is the precondition. Permanent windbreak technology has to be weighed against other options for solving the problem of wind stress. Particular sensitivity is required not to displace other traditional microclimate management techniques.

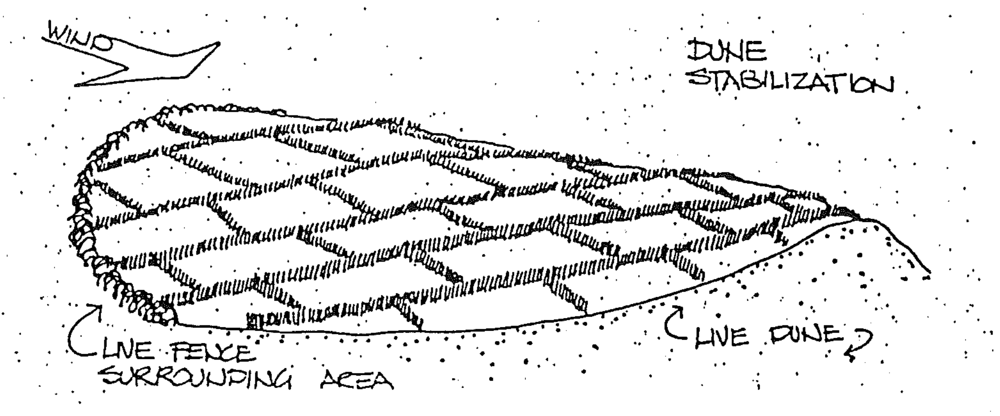


Figure 44: Hedges in sand dune stabilisation (381)

3.10.7 Role of hedges in sand dune stabilisation

Severe wind-erosion as well as important through-transport of sand is a threat posed by drifting sand and migrating dunes to settlements, farmland, buildings, installations, roads, and land. Sand stabilisation is an important aspect of revegetation and conservation activities in arid areas. A good deal of information exists on sand dune stabilisation (literature review 156, A, short summary 381). Among the biological methods, brushwood or living fences can be used. Species such as Euphorbia balsamifera can be successfully regenerated from cuttings, even in low rainfall areas. Freshly cut branches of Euphorbia balsamifera are partially buried in rows of shallow trenches (381). One option of how to integrate live fences is depicted in Figure 44. Species suitable for sand dune stabilisation include Casuarina equisetifolia, Prosopis juliflora, Tamarix aphylla, to name a few. Many local plants are very suitable

Remarkable systems of screens for sand-dune protection have been developed, e.g. by farmers near Kaifeng in China. The screens are planted at fairly close intervals. They vary with the degree of susceptibility which the soil shows to wind erosion and with the density and height of the screen. Single rows of willows have an average height of 12 feet (4 m). They are planted not more than 60 feet (20 m) apart. The farmers have found that single rows of trees are more suitable than double or multiple rows, for they occupy the least amount of space for the amount of protection which they offer (120). Much can be learned by inspecting what local people have done to fight sand encroachment. For instance, in the arid north of Sudan, some farmers first establish one row of dead date palm leaves and one row of wheat stalks to catch sand and thus protect the *Prosopis chilensis* windbreak which is planted later on the leeward side (215a).

3.10.8 Some problems that may occur when growing hedges for wind protection

Some soils may be too shallow and rocky to support growth of trees large and tall enough to create an effective windbreak.In arid areas, inspite of its greatest potential, innital watering of the hedge is required, which resource poor people may not be able to afford. Problems associated with field windbreaks include shade, competition for soil moisture and nutrients, harbouring of pests and diseases and interference with farm machinery.

Land may be scarce, and the cost of windbreak protection from grazing may be high. To protect windbreaks from encroaching animals may be a very serious problem. Livestock may trample the windbreak in order to obtain fodder or shade. In agricultural schemes with no fixed tenancy or where the plots are rotated every year, only annual windbreak hedges can be erected. In areas where shifting cultivation is predominant, or the area is too degraded to justify (private) investments, windbreaks may eventually protect only abandoned land. Finally, farmers may be too resource-poor to erect shelterbelts (time factor). Hedges can be an interesting starting point with a few incentives. They can be promoted on a small scale.

3.11 Hedges as an ecosystem

"Hedges provide a partial substitute for lost woodlands. They are essentially forest edges without the forest, forming an "ecotone" or border area between two other ecosystems. Ecotones often share many of the creatures of both other systems and so are doubly rich in wildlife." (56)

Previous chapters have been concerned with hedge issues separately. This approach has had its merits in serving to highlight essential aspects. In this chapter the focus is on hedges as an ecosystem. Benefits and problems of hedges including the pest and disease complex will be discussed. An ecological perspective can be useful for a better understanding of hedges as a natural ecosystem. This is not an end in itself. Hence some practical implications for wildlife management, particularly as it suits resource-poor land users, will be discussed as well.

3.11.1 Ecological role of hedges

In western countries hedges are increasingly being discussed from a conservational point of view and as regards their role in landscape amenity (211). Discussion of issues associated with nature conservation is often clouded by a misunderstanding of the meaning of the term and its confusion with preservation which is definitely not the same thing. Conservation is a dynamic approach: it aims as far as possible to take all relevant ecological factors into account. Conservation involves active management (93).

No matter whether poor people are concerned or not, they cannot afford the luxury of conservation along western lines. Hence ecological benefits of hedges have to be immediately translated into economic results. This is the most likely way that they can be accepted by poor land users.

Hedges can perform various ecological roles. For instance, they prevent or reduce degradation of the natural resource base of regions and resource-poor land users. Some aspects of the environmental role of hedges for soil conservation (3.8, 3.10) and microclimate enhancement (3.9) have already been discussed in detail and need no further elaboration.

From an ecological perspective hedges can, in specific circumstances, be

- a very beneficial ecosystem,
- an important ecological reservoir (wildlife),
- a refuge from the effects of intensive agriculture.

Beneficial ecosystem

It has been claimed that hedges help to stabilise ecosystems, but concrete evidence to support or refute such a statement for tropical systems is difficult. Reasons include:

A hedge can be a very naturally oriented ecosystem; some are extremely artificial like a heavily trimmed ornamental hedge or a one-species hedgerow in alley cropping.

Ecotones: Natural hedges have been amply described as "a linear forest" (56). A multistorey natural hedge consisting of trees, shrubs, and herbs is similar to the edges of naturally oriented forests. These two forest edges together form a "hedge forest".

In some cases hedges are not backed by forests, so plants and animals which need blocks of forest cannot use the hedge ecotone. On the other hand, those species that already preferred edge conditions have been able to dominate hedges more readily (44) (see Figure 45).

A hedge, when sufficiently large and consisting of various "native" plants, can be an ecological niche, i.e. serve as a habitat for animals and plants.

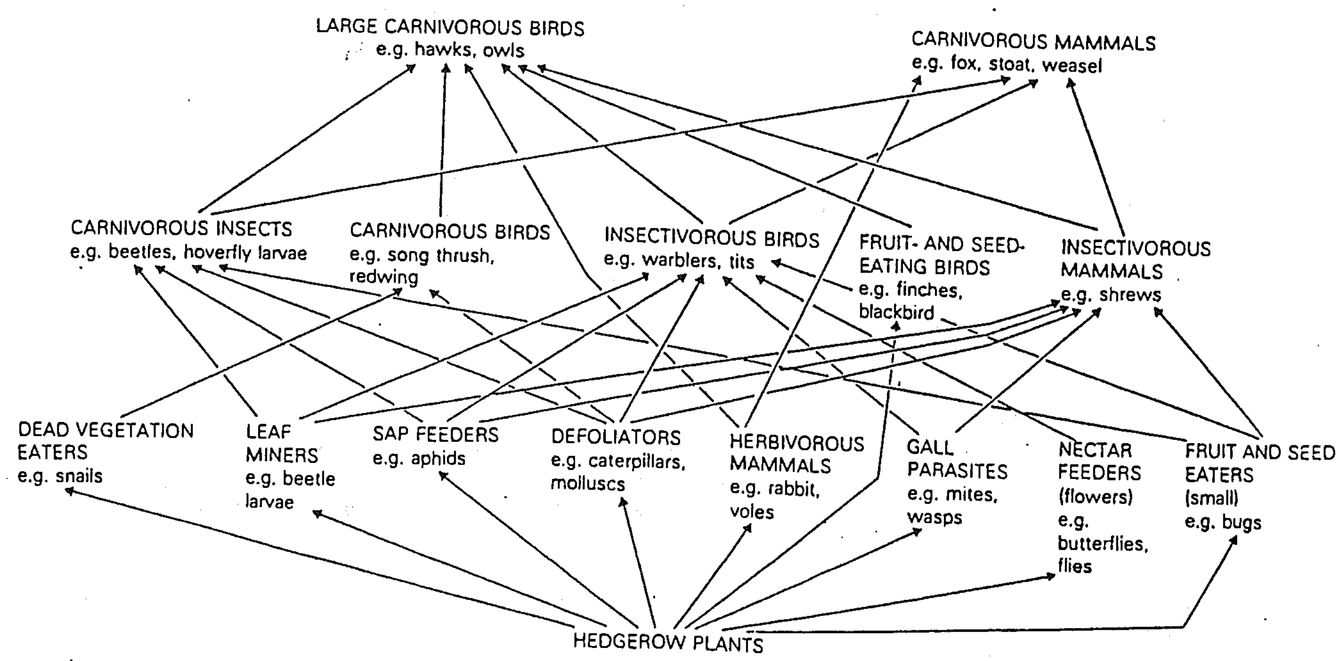


Figure 45: Some ecological niches and food relationships in hedgerows (93)

Hedges are important ecological reservoirs

Habitat for plants: When the primeval vegetation has been cleared this is a threat for many wild plants. Extinction may be the result. Some woodland species have been able to adjust to the new environment and have survived in hedges; others have succumbed, their place being taken by sun-loving forms (93).

A great variety of wild plants can eventually find their place in a hedge. This can help prevent extinction of certain plants. At ground level a hedge, if relatively undisturbed, provides space compared with the fields around it. Species like herbs which take advantage of sunny protected locations rather than species of the deep wood can find a habitat there (44). This may be the right place for specific medicinal herbs, etc.

3.11.2 What research and development activities exist?

Tropical hedges as an ecosystem have hardly been studied. Thus few ideas exist about the scale of their influence on biological control and their role in wildlife management. In our present state of knowledge the maintenance of diversity is the wisest policy for farmers (93).

A great body of studies in industrialised countries has demonstrated the great value of hedges as an ecosystem: there is also scientific and empirical evidence that hedges support the balance of agroecosystems. The impact of hedges in controlling pests and diseases has not been studied sufficiently, even in industrialised countries (93). Generally very few studies have quantified the dynamic relationship between pest population and natural enemies in farming systems.

The influence of hedges on the antagonistic fauna in the neighbouring fields has rarely been tested. One relevant study in West Germany confirmed the beneficial role of hedges. A reduction in the cost of pest control was demonstrated (342).

In the tropical environment there are very few studies available (for one exception see below). Many site-specific or ecofarming projects assume that hedges are very important for an ecological balance. No negative experience with regard to pest problems provoked by hedges has been reported (100). It seems that hedge plants do not pose any special pest problems different from those in other forms of permanent land use.

The role of hedges in wildlife conservation does not seem to be a topic at all so far in research and development. This theme is addressed indirectly in the wildlife management discussion on the great importance of maintaining the "edge habitat" (ecotone), e.g. (317). Their potential role in sustainable game management may be interesting to investigate.

3.11.3 Well known species

There are many shrubs which encourage wildlife. Some have a particular attraction for bees and butterflies (see Chapter 3.3.6 and Table 52). Birds can also be attracted by *Berberis spp.*, *Buddleia spp.*, *Cotoneaster spp.*, *Eleagnus spp.*, *Ilex spp.*, *Rhus spp.*, to name a few shrubs.

3.11.4 Hedges and pest control

The management of pests (phytophagous insects, pathogens and weeds) is accepted as a very important aspect of any agricultural development strategy (122). Pests and diseases are complex and site-specific. Some of the benefits and disadvantages often associated with hedges include:

- beneficial role in biological pest control and as a source of natural pesticide,
- hedges can pose problems if they are reservoirs of weeds and crop pathogens and herbivorous mammals.

Controversal perceptions of role of hedges

It is not the problem per se which matters but how it is perceived. Given the present underdeveloped state of our knowledge a note on different perspectives is warranted.

Farmers and land use planners often state or assume that hedges harbour pests and diseases (116, 44). Some of the problems commonly associated with border tree planting include diseases and crop pests (especially birds and rodents). In Rwanda and in other parts of Africa, farmers appreciate *Euphorbia tirucalli* as a refuge for useful insects, which biologically control pests and diseases. Unlike other species which harbour pests, *Prosopis spp.* for example, has the reputation of favouring the infestation of crops near the tree by nematodes. Ranchers in Costa Rica believe that *Gliricidia sepium* provides protection against certain pests (20). Sometimes farmers do not like to plant the physical nut (*Jatropha curcas*), a very common hedge plant, because of the fear of snakes (164a). This was also one objection to a security hedge of *Acacia mellifera*, a widely accepted security hedge, around irrigated gardens in the Sudan. It is interesting to note that most of these arguments against snakes were put forward by people who had never planted a security hedge.

In other parts of the Sudan, the objection to retaining of any kind of vegetation strips in large-scale mechanised farming is also based on the fear that the Dioch (*Quelea quelea*) and a dove (*Strephopelia spp.*) may cause damage to the crops (215a). Mexican floodplain farmers do not classify cottonwood and willows adjacent to their fields as "weed trees". They are aware of the importance of hedges in pest control (see case study 3, Appendix 1).

When pesticides are available and affordable they are even preferred by small-scale farmers. From a short-term point of view they may be more economical than other means. This can also be a constraint on using mulch from alley cropping (see 3.7).

Biological control

In recent years the biological control of insect pests, i.e. the use of their natural enemies (parasites and predators) has received much attention. However, scientific knowledge on the role of hedges is scare. Their role has hardly been studied. An understanding of the full environment of hedges is of vital importance for the inclusion of hedges in developing pest control strategies.

One of the very rare surveys on insect pests in alley cropping has been made in dry zones of Sri Lanka. The alley cropping systems under study consisted of *Leucaena leucocephala* and *Gliricidia sepium*, maize and cowpeas, cultivated under tilled and nontilled conditions. Surveys on insect pests and their natural enemies carried out when the crop started flowering and podding revealed the following:

It was found that damage by *Maracu testulalis*, which is the most prevalent pod borer, was the lowest in the Gliricidia avenue compared with fields with no avenue crops, Leucaena avenues and monoculture of cowpeas. Also the young branches of *Gliricidia sepium* were heavily attacked by *Maruca testulalis*. Therefore in grain/legumes cultivation *Gliricidia sepium* could be a good trap crop to attract insects or divert them from the principal crop and encourage reproduction of parasites and predators. This can result in a better biological balance between the pest and its natural enemies.

Hedges in alley-cropping may help in various ways to reduce the size of insect population and severity of damage. They may positively modify the microclimate for natural enemies of the pests of agricultural crops. All parasites and predators require several resources in addition to the host insect.

In many cases supplementary food and suitable habitats are lacking or in short supply for the parasites and predators to survive in order to attack a given host effectively. For example: the adults of hymenopterous parasites of legume pests require nourishment to lay eggs or to live even for a short period of time. Many of them have to feed on nectar or flowers. Flowers of hedge trees such as *Gliricidia sepium* and Leucaena could provide a good source of nectar within their flying range. The activity of predators and parasites is checked when the crop is exposed to high temperatures. The provision of shade by hedge plants can enhance their activities and also protect them from the full effect of high winds and rain (125).

Species

Only a few species have been reported which may harbour pests like *Prosopis spp.* in the arider and *Thephrosia spp.* in tropical mountains. (248). One simple reason for this may be the underdeveloped state of knowledge or that this is not a great problem.

A review of main pests which are encountered in browse plants in Africa may be relevant for hedgerow growing as well. They include: plant parasites: Phoelipaea (Orobanchaceae) on *Atriplex spp.*, a root parasite; Loranthaceae on *Acacia spp.*: Tapinanthus spp.

Insects: Acrididae: weevils (on the fruit of African acacias, especially *Acacia tortilis*); Cochenilles: *Dactylopius opuntiae* on cacti; Lepidoptera: the cactus moth: *Cactoblastis cactorum*. Mammals: rodents: Psammomys obesus on *Atriplex spp.* and cacti (175).

However, the danger can only be assessed for a concrete situation and site. The previous note on some aspects of hedges as an ecosystem indicates that further surveys in this direction will be of limited relevance.

Some potential problems of hedges

Common complaints against hedges are that they can be reservoirs

- of crop pathogens and weeds, and of
- herbivorous mammals.

Reservoir of crop pathogens and weeds: Hedges can harbour disease vectors and pathogenic organisms. Many diseases of agricultural crops are known to be transmitted by insects. This can result in a reduction in crop yield. Two factors have been shown to play a part in determining the severity of an attack by insects: wind speed and density of insect predators. Variations in wind speed evidently have a considerable influence on the rate of spread of the disease, due to the effect of the powers of dispersion of the winged aphids. Comparisons of open fields and ones enclosed by hedges have revealed striking differences in the densities and rates of dispersion of aphid carriers (vectors). A second factor of importance has been the density of insect predators, particularly the carnivorous larvae. There is no doubt that hedges harbour a vast number of potential insects such as aphids and defoliating caterpillars. These are usually held in check by an equally large range of insectivores, both invertebrate and vertebrate. How these two entities will interact depends on a particular situation. Most insect pests associated with hedges are forest and forestland edge organisms which have successfully adapted to the cleared agricultural landscape. Except where hedgerows provide a specific alternative host it is difficult to assess their precise effect on pest population (44).

Weeds: Strips of vegetation which could otherwise serve as windbreaks are often burned in East Africa with the aim of destroying weeds (215a). The tendency to blame hedges as a source of arable weeds is unfounded, as far as annual weeds are concerned. These weeds are specialised in invading disturbed ground, while the characteristic ground flora of hedges is made up of perennials. Hence spraying the hedge bottom with total weedkillers, is inappropriate, because it will destroy many harmless plants and associated invertebrates (44, 93). On the other side, many hedge plants are potentially aggressive pioneers, which may be very invasive. This is particular true of exotic species. Indeed many agriculturists object to plant species like *Prosopis chilensis*, because they will fear that they invade their fields. However this is more a management problem (215a) (on the pros and cons of exotic species see Chapter 5). Woody species which do not propagate easily by seeds have to be considered. A study in Thailand on *Mimosa pigra* concluded that due to its weediness, it should not be used as a live fence (305a). What is a weed and what is a resource depends on the context.

Herbivorous mammals: Hedges can house considerable populations of herbivorous mammals. For instance, rabbits and voles can be a nuisance. As indicated above hedges also house a range of carnivores that rely on small rodents for their prey and assist in controlling their density. These include mammals such as fox, weasel and birds of prey (like owls). The use of universal herbicides to kill all the vegetation around the edges of fields and the base of hedges is harmful in eliminating the habitats of beneficial mammals (108). There are climatic regions in which pest and disease problems are primarily regulated by antagonisms and not abiotical factors like climatic rest periods. In such a situation the maintenance of habitats in which this antagonism can develop is of particular importance (248). Hedges can support this plant protection. If plant protection is the most critical issue a relative simple system of alley-cropping-specific (maize-leucaena) pests and diseases can easily develop in the hedges. Therefore a greater diversity of woody plants is desirable. The disaster with Psyllid on Leucaena was a clear demonstration of this.

3.11.5 Wildlife value of hedges

Management of wildlife in general is concerned with the manipulation of population, either directly by controlling their number or indirectly through a modification of their habitat. Generally animal populations are more vulnerable to manipulation of their habitat (317).

State of knowledge

There is a consensus (among ecologists) that hedges are a miniature ecosystem which offer a habitat for a variety of animals, unlike monocultural forestry plantations. In a world of accelerated disappearance of natural forests hedges are advocated as one approach to habitat networking (32).

The claim that hedges provide valuable corridors for wildlife (e.g. 32) is the subject of controversial discussion. This function can be essential for the dispersal of animal population and their distribution over a wide area; thereby avoiding excessive competition for available resources. It seems to be of no more than secondary ecological importance (93).

Hedges and wildlife management

Hedges offer a wide range of ecological niches. The nature and extent of niches depends on a variety of environmental factors, such as the proportion of trees, hedge length, width, and height, the existence and density of vegetation to mention only a few (93). When conservation practices are applied to the land, the habitat in the area is improved for birds and animals. Planting hedges and revegetation will increase wildlife in the process

Apart from the general consensus that it is possible to attract and increase wildlife in hedges, there are hardly any scientific guidelines in the tropics, particularly for the specific context of the poor.

In temperate zones sufficient knowledge exists on attracting and keeping several desired animals in the hedge. Bees are attracted by plants growing in the rim of a hedge, when there is always something flowering (32). In apiculture a year-round supply of bee forage is essential for poor people; they cannot afford to buy syrup etc. to bridge the period without bee pasture. Specially designed natural hedges are one approach.

Wildlife conservation which is not translated into economic results may be unacceptable to poor land users. The role of hedges in butterfly farming has already been mentioned. Sound wildlife management can be important for the poor. Any starting point has to be the interest and need of the people. For instance in the North-East of Thailand, wild lizards are regarded as an attractive food source. School children are keen on hunting them. Hence a proposal has been made to give incentives for hedgegrowing on school grounds in which wild lizards can find a habitat. Efforts in this direction can evolve into a very valuable environmental education process with tangible results. Active and attractive management are the key to the acceptance of sound wildlife management.

3.11.6 Some problems that may occur when promoting hedges for nature conservation

The conservation of hedges frequently requires the reconciliation of conflicting viewpoints. Farmers tend to regard them as a liability, while conservationists are anxious to promote their survival as sanctuaries for wildlife and an amenity. The present state of knowledge and awareness among planners is very restricted and it is not an easy situation to remedy. Ecologists are more interested in ecosystem hedges while planners are not convinced of their positive impact.

The mainstream of agricultural development is oriented towards western farming models (planners and agronomists in developing countries see hedges as a sort of backwardness). Hedges can be a constraint on the operation of large agricultural machinery. The application of universal biocides can be a threat to hedgerow growing.

4. SOCIAL AND ECONOMIC ISSUES IN HEDGEROW GROWING

Hedges are not a panacea for problems of land use management and the needs of resource-poor people. An understanding of the social, economic, cultural, and historical context of hedgerow growing, particularly for resource-poor people, is an important prerequesite for evaluating the hedge-specific potential. The following discussion summarises important issues; some have been dealt with under specific uses in Chapter 3. Chapter 4.1 discusses social, cultural, and socio-economic, and Chapter 4.2. economic issues related to hedgerow growing. More research and development of hedgerow systems is required. Chapter 4.3. briefly deals with this issue.