4.7 Multi-seasonal intensive fallowing

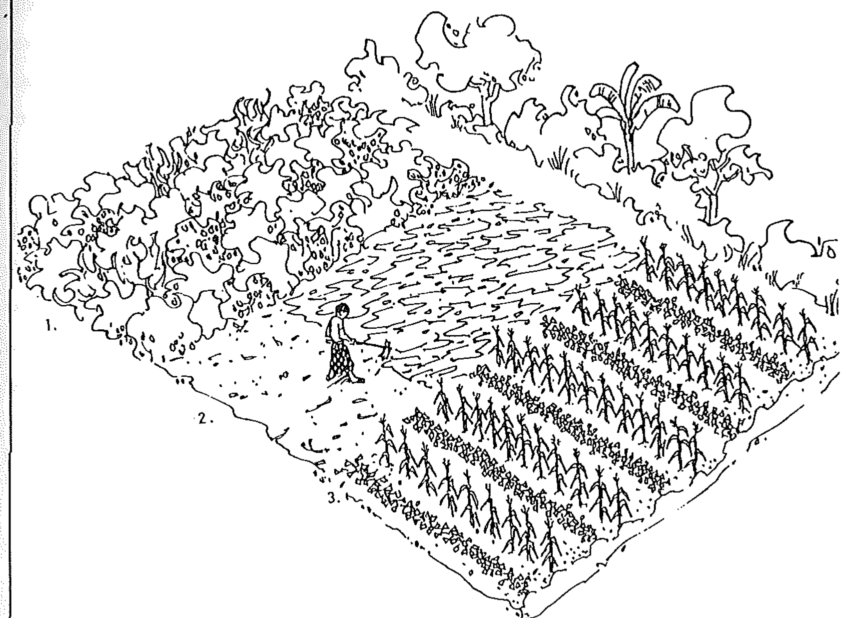
Under current population pressure, long fallow periods are no longer possible in many areas. In such areas fallowing has been either dropped altogether or so drastically shortened that its purpose is not achieved (NYE and GREENLAND 1960; AGBOOLA 1981; and others). Curtailed fallow periods or pasture fallows cannot prevent the continuing decline in soil fertility (NWOBOSCHI 1981; RAMAKRISHNAN and TOKY 1981). In fact they may even encourage the process (ROOSE 1981; LAUER 1956).

The multi-seasonal intensive fallow is based on the idea of substituting a naturally occurring fallow with a deliberately cultivated one. The aim is both to increase the quantity of biomass and to improve its quality.

An **increase in biomass** is seldom achieved, since the natural fallow is usually so well suited to the site that a new mixture of plants is unlikely to do better. It is somewhat easier to improve quality. Natural fallows are mainly composed of Gramineae and Compositae. These plants do not do much to replenish the soil with nutrients. In contrast, an association rich in legumes can at least enrich the soil with nitrogen. In a number of cases, cultivating legumes has also been found to increase the availability of phosphorus (KAHNT 1983; AGBOOLA 1975). Furthermore, the depth of rooting by subsequent crops can be markedly improved by growing suitable fallow plants, and plant species that continue to grow in the dry season (see below) can mobilize additional reserves (EGGER 1982).

Plant composition. Bush fallows should consist of a combination or association of different species so that they are ecologically stable. Besides making better use of water and light, mixed stands are better able to access nutrient reserves in the soil. The micro-organisms characteristic of the root zone contribute greatly to this process. This broad capacity to assimilate nutrients becomes especially important where nutrient availability is poor (KLAPP 1967)(see Figure 4.2).

Figure 4.2. Green manuring with a multi-seasonal intensive fallow



1. Two crop cycles with a sown mixture of green manure plants (shrubs, perennials, herbs); 2. Lopping the stand, and incorporating the wilted plant material into the soil; 3. Cultivation of intensive annual crops.

As part of an agricultural development project in the Nyabisindu Region of Rwanda[70], a method of intensive fallow was developed that could be used on poor and sites where the seasonal *Mucuna* fallow had proved unsatisfactory.

According to project data, the intensive fallow should last at least two growing seasons (10 months) but not longer than 18-24 months, because the growth of biomass after flowering is much slower than before (PIETROWICZ and NEUMANN 1987). The

[70] For details, see Section 3.5.2.

regional agricultural extension officers recommend that farmers integrate a regular 10-month intensive fallow into their crop rotation. To maintain soil fertility, this should be done about every four years. The farmers, however, employed this technique only on their most exhausted fields, where little or no further agricultural production was possible. On such land the biomass growth, and hence the regenerative effect, is much slower, so they needed a longer fallow period of at least two years, sometimes even three (RAQUET 1990).

The mixed fallows used in the project's research consisted of *Tephrosia vogelii, Cajanus cajan* and *Crotalaria lachnophora* (Combination I) or *Crotalaria pallida* (Combination II).[71] *Desmodium* spp. and *Sesbania micrantha*, which were also originally included in the mixture - the first to cover the soil and the second to create an above-ground layer - did not prove worthwhile and were dropped. A climbing legume was sought as a useful supplement to the mixture, but without unqualified success. The best candidates were *Canavalia ensiformis, Dolichos lablab* and *Phaseolus lunatus*.

These associations can be sown during the short rainy season or even at the beginning of the long rainy season. Some farmers sowed successfully at the end of the long rainy season. The seed is planted near the surface, 2-4 cm deep. Weeding is not usually necessary. During the short rainy season the fallow springs up, together with associated weeds (*Bidens pillosa, Ageratum conycoides, Tagetes minuta, Galinsoga parviflora*). At the beginning of the long rainy season it develops into a dense, thriving stand. At this point the fallow is cut over and the plants are left to wither for two weeks. Woody stems, from which the leaves fall or are easily shaken off, are collected for firewood. The remaining plant material is plowed under to decompose in the moisture still left in the soil and with the first rains of the next rainy season. Unfortunately this does not always work; sometimes there is too little residual moisture in the soil or the next rainfall comes too late.

[71] The associations used in the trials were as follows: *Cajanus cajan*, 450 g/100 m² (TKG 150 g); *Tephrosia vogelii*, 260 g/100 m² (TKG 52g); *Crotalaria* sp., 160 g/100 m² (TKG 23 g); *Sesbania micrantha*, 50 g/100 m² (TKG 52 g); *Desmodium intortum* and *Desmodium uncinatum*, 13 g/100 m² (TKG 3.2 g). These seeding rates produce about 100 plants/m² and can be substantially reduced without impairing ground cover (PIETROWICZ and NEUMANN 1987).

Table 4.9. Composition and yields of two intensive fallow plant associations* after eleven months of growth, Nyabisindu, Rwanda**

	Plants/m²		Above-ground biomass (t DM/ha)	
	Association I	Association II	Association I	Association II
Cajanus	3.9	3.7	1.44	1.49
Crotalaria	13.9	17.2	5.73	2.15
Tephrosia	11.6	12.3	3.04	4.52
Total	29.4	33.2	10.21	8.16
			(5.69-15.45)	(3.83-14.96)

* Association I: *Cajanus cajan, Crotalaria lachnophora, Tephrosia vogelii* and *Desmodium uncinatum/intortum*; Association II: as I but with *C.pallida* instead of *C.lachnophora*.
** Mean values from 9 trials with 3-6 replicates on farmers' fields in Kavumu, Nyabisindu.

Source: RAQUET (1990)

As Table 4.9 indicates, the more successful Association I produced a biomass growth of about 6-16 t DM/ha in about 11 months (RAQUET 1990). A high proportion of this was stems, the bulk of the leaves having already fallen and become mineralized. A further 8 t DM/ha might therefore be estimated for the leaf litter, which regrettably was not measured. Comparing the two associations, it was clear that the proportion of leaves in Association II was greater.

Table 4.10. Composition of the biomass from an eleven-month intensive fallow and its growth performance compared with a natural fallow in Nyabisindu Region, Rwanda*

Components	Association I**		Association II**	
	t DM/ha	(%)	t DM/ha	(%)
Stem	9.57	(69)	7.92	(66)
Leaves	0.71	(5)	1.45	(12)
Fallen leaves	2.97	(22)	2.12	(17)
Weeds	0.57	(4)	0.58	(5)
Total	13.82	(100)	12.07	(100)
Natural fallow	4.42 t DM/ha			

* Nyirabanguka field trials, data from four replicates. Measured only until the time of harvest.
** Association I: *Cajanus cajan, Crotalaria lachnophora, Tephrosia vogelii* and *Desmodium uncinatum/intortum*; Association II: as I but with *C.pallida* instead of *C.lachnophora*.

Source: RAQUET (1990)

The longer the intensive fallow lasted, the more apparent became the differences between the two associations and the greater their superiority over a natural pasture fallow (Tables 4.10 and 4.11). The results also show that the growth in biomass slows down markedly after three cropping seasons (Association I), or may even become negative (Association II). These values reflect only the above-ground, living biomass. In addition, the last measurement followed a protracted dry period during which many leaves had already fallen.

Table 4.11. Yields of above-ground living biomass from an intensive fallow after growing periods of various durations, in Nyabisindu Region, Rwanda*

Duration of fallow	Biomass yield (t DM/ha)		
	Natural fallow	Association I**	Association II**
2 cropping seasons	5.77	26.62	24.97
3 cropping seasons	14.42	42.90	41.41
4 cropping seasons	6.34	46.21	32.80

* Mean values from 9 trials with 3 - 6 replicates on farm fields in Kavumu, Nyabisindu.
** Association I: *Cajanus cajan, Crotalaria lachnophora, Tephrosia vogelii* and *Desmodium uncinatum/intortum*; Association II: as I but with *C.pallida* instead of *C.lachnophora*.

Source: RAQUET (1990)

The legume associations produced a yield increase of 20-40% in the first subsequent cropping season and, in some individual cases, increases of as much as 125% and 390%. In contrast, the results obtained in the second season, with values of -46% to +28% as compared with the control, were not so positive (PIETROWICZ and NEUMANN 1987). In further trials it was found that performance at impoverished sites differed from that at sites with so-called "average" soil fertility (Table 4.12). On the impoverished sites, a definite improvement in yields of around 25-46% became apparent only in the second subsequent cropping season, whereas on average sites an earlier and stronger effect was measured in the first season (75% and 68%). Interestingly, Association II was not less effective than Association I, despite producing less biomass.

Table 4.12. Effect of an eleven-month intensive fallow* on yields of following crops in Nyabisindu Region, Rwanda

Quality of the site		---- **Yield (kg/ha)** ----		
Crop period	Crop	Natural fallow	Association I	Association II
Marginal site				
1st cropping season:	Mixed crop			
	Maize	280	310	270
	Beans	n.m.**	n.m.	n.m.
2nd cropping season:	Sorghum	610	760	890
Average site				
1st cropping season:	Mixed crop			
	Maize	970	1700	1800
	Beans	740	500	700
2nd cropping season:	Sorghum	750	890	810

* All of the biomass was incorporated; ** n.m. = not measured

Source: RAQUET (1990)

According to DRESSLER (1983), the same productivity can be achieved on a site using the rotation system with intensive fallow as can be obtained from applying 15 t/ha of stable manure per year.[72]

[72] The economic efficiency of intensive fallowing is discussed in Section 4.12.

In southern Nigeria, KANG and OKIGBO (1981) observed that where the fallow cycle was becoming ever shorter under the influence of population pressure, farmers stopped cutting and began encouraging certain shrub species (*Anthonata macrophylla, Acioa baterii, Alchornea cordiflora* and *Gliricidia sepium*) in order to intensify the shorter fallows.

The Wakara, on the island of Ukara in Lake Victoria, practise multi-seasonal intensive fallowing using *Crotalaria striata*. This is first undersown with millet and then left in the fields for some 9 months, after which it is deeply plowed under with stable manure compost. Some 25% of the rotation period is devoted to this fallowing phase (LUDWIG 1967).

In the light of trial results from Rwanda, multi-seasonal intensive fallowing deserves more consideration in future. At the International Institute of Tropical Agriculture (IITA) in Ibadan, Nigeria, trials are presently being carried out with different tree and shrub species. Initial results indicate that more than one growing period is necessary for *Leucaena, Gliricidia sepium* and *Cajanus cajan* to have a lasting effect on the "field ecology". *Gmelina arborea, Cordia alliodora, Albizia falcataria, Samanea saman* and *Cassia siamea* are also being investigated (IITA 1981; GETAHUN 1981). An effect similar to that of an intensive fallow was achieved on an Ultisol in the Amazon Basin in Peru with *Pueraria phaseoloides*. Alternating a two-year *Pueraria* fallow with one crop year (up to three harvests during the year) produced yields that equalled those achieved after a 25-year forest fallow (SANCHEZ et al. 1982).

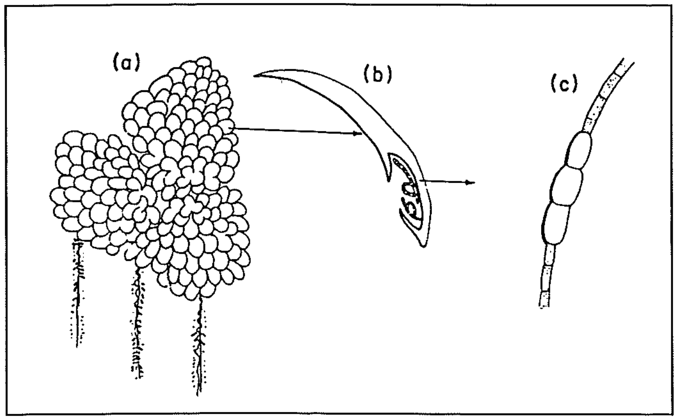
4.8 Green manuring with Azolla in rice

Another important method of green manuring involves the use of Azolla with rice.[73] The method is based on the association of the Azolla sp. of water fern, which grows on the surface of shallow water (5-15 cm), with the blue-green algae *Anabaena azollae* Strasburger. The algae grow in cavities of the fern's leaves and are capable of fixing

[73] As the *Azolla* are discussed extensively in the literature (HAMDI 1982; FAO 1979a; FAO 1979b; IRRI 1979; GUTBROD 1982), the report here is confined to the essentials.

considerable amounts of nitrogen, which they transfer to the fern (Figure 4.3). The fern thrives in turn, in providing an excellent habitat for the nitrogen-fixing algae.

Figure 4.3. a) Water fern *Azolla pinnata* R.Br. (x 10), b) Leaf with cavities and blue-green algae, c) *Anabaena azollae* Strasburger (x 1000)



The roots of the fern (a) hang loose in the water and can take root in mud. The plant dies if it loses contact with open water (GUTBROD 1982). Six species of water fern are known, of which *A. pinnata* and *A. filiculoides* are the most economically important.

Growth conditions. Azolla flourish at temperatures of 10-30°C. The optimum for *A. pinnata* is about 25-30°C (FAO 1979a), while *A. filiculoides* does best under 25°C (16-21°C) (GUTBROD 1982). Azolla cease to grow at 5°C. Depending on provenance and species, the demand for light is about 18,000-45,000 lux in the optimum range (approximately 50% of full daylight). The pH value should be 5-7. Salinity impedes azolla growth, the best content being 0.1%. The plant dies at 1.3% salinity (HAMDI, 1982). The optimal relative humidity for Azolla is around 80-90% (FAO 1979a).

The P content of the water is generally a limiting factor for Azolla growth (GUTBROD 1982). Crops grown with Azolla are therefore provided with 10-12 kg of P_2O_5/ha every 2-5 days in China (HAMDI 1982; FAO 1979a). Applications of 1000 kg/ha of stable manure every 10 days, of semi-liquid manure (125 - 250 liters every 5 days), or of compost have also been used in China. Applications of potash may be necessary on light, acidic soils.[74] Molybdenum is an important micronutrient for fixing nitrogen.[75]

Because pests or diseases may occur with intensive propagation, the use of pesticides is frequently recommended (see HAMDI 1982 and CHU 1979). When necessary to protect the parent crop, and following a qualified analysis and field survey, Carbufuran and Malathion can be applied. However, in China, temporarily suspending the water supply has also proven effective in controlling pests. Protecting and encouraging predatory frogs and spiders is useful. The ant *Tetramorium guineense Farbicus* can keep down Lepidoptera by up to 67% (CHU 1979). Ducks, too, attack snails and other pests on Azolla ponds (FAO 1979a). Azolla are especially susceptible to disease and pests during the hot season.

There are three ways in which Azolla **can be used as green manure:** as a preceding crop, as an undersown crop, and as a subsequent crop. No matter what method is used, it is necessary to establish special plant beds for Azolla[76]. In China, large numbers of basins 3-4 m^2 in size are established and compost is added (see Figure 4.4). For *A. pinnata* an inoculum of 0.7 kg fresh matter/m^2 is given, which doubles its weight in 3-5 days. This species reaches its optimal density in 7-15 days, when the plants begin to overlap (2.2 kg/m^2 or t/ha). At that point they can be harvested. *A.filiculoides* is inoculated with 0.5 kg/m^2 and doubles itself in 7-8 days, so that 6.0 kg/m^2 is produced in about 30 days. (This species can continue to grow vertically up

[74] 100 kg of ash supplies approximately 10 kg K_2O and many trace nutrients.

[75] In the form of Na_2MoO_4 x 2 H_2O as fertilizer.

[76] During hot and cold periods, special measures must be taken to save the Azolla stand for the next season; there is still no method of generative propagation (see FAO 1979a and 1979b, and HAMDI 1982). To protect against overheating (water temperatures above 40°C), Azolla can be shaded beneath high-growing rice. Shallow ponds surrounded by trees are also suitable; artificial shade canopies are another possibility. For details on cultivating Azolla in nutritive broth in the laboratory or in greenhouses, see HAMDI (1982).

to 15 cm high, whereas *A.pinnata* cannot.) The inoculum thus propagated is applied to the "irrigated fallows", where it then grows to maturity.

SINGH (1979) describes the Indian method of green manuring using Azolla. According to this method, fresh Azolla is broadcast in water 5-10 cm deep (about 100 g/m^2). With a light application of phosphate fertilizer (best spread at 8-10 kg P_2O_5/ha), *A.pinnata* will cover the entire field in 10-20 days. When the water is drained off, the Azolla is turned into the soil and rice planted within the week. Incorporating the Azolla always produces a better effect than simply leaving it to decompose as is often practised when the crop is undersown. When little water is available, Azolla can be grown in small areas such as ponds and ditches and harvested weekly (always leaving some inoculum). Covering 5% to 10% of the area to be planted is sufficient to fertilize the whole in 2-3 months.

In China, *A.pinnata* is cultivated as a preceding crop, as an undersown crop and as a catch crop (FAO 1979a and 1979b; HAMDI 1982). The procedure when growing *A. pinnata* as a preceding crop is to inoculate the area with 0.5-0.8 kg/m^2.[77] The water is drained off after 6-15 days, the Azolla green manure is incorporated (using a small tractor or manually) and the rice is transplanted immediately afterwards. On less fertile soils, incorporation can be repeated two to three times (quickly flooding the field after incorporation minimizes N loss). Azolla supplies some 30-40 kg N/ha per harvest.

In the undersowing method, 0.5 to 0.7 kg of Azolla is spread per m^2 after the rice planting. It is then worked into the rice paddy by hand every 10-15 days, always leaving sufficient inoculum. This procedure is repeated three to five times until the panicles emerge. (Leaving a floating layer of Azolla can lead to oxygen deficiency and damage to the rice.) Adopting this practice could increase the rice yield in some provinces from 3600 to more than 9000 kg/ha. Table 4.13 shows the somewhat less dramatic results obtained by CHEKIANG (1964, in CHU 1979).

[77] For enough inoculum to be available, propagation must start about 1 month previously; a propagation area of 120 m^2 per ha is used.

In the double-row method, the rice is planted out in double rows (13 x 6.5 cm). Between the double rows a space of 55 to 65 cm is left in which the Azolla is cultivated (Figure 4.4). The grower must walk through the rows weekly, beating the Azolla with a bamboo broom to disentangle the plants from one another so that they can continue to grow. When the first rice crop is mature, the water is drained off to strengthen the Azolla.

With this method it is possible to grow rice and Azolla almost throughout the year. Especially suitable for this technique are rice varieties that grow compactly, with upright, thin leaves, a large number of grains per panicle and good tillering ability.

Table 4.13 Effect of timing and frequency of Azolla incorporation on the yields of Azolla and rice

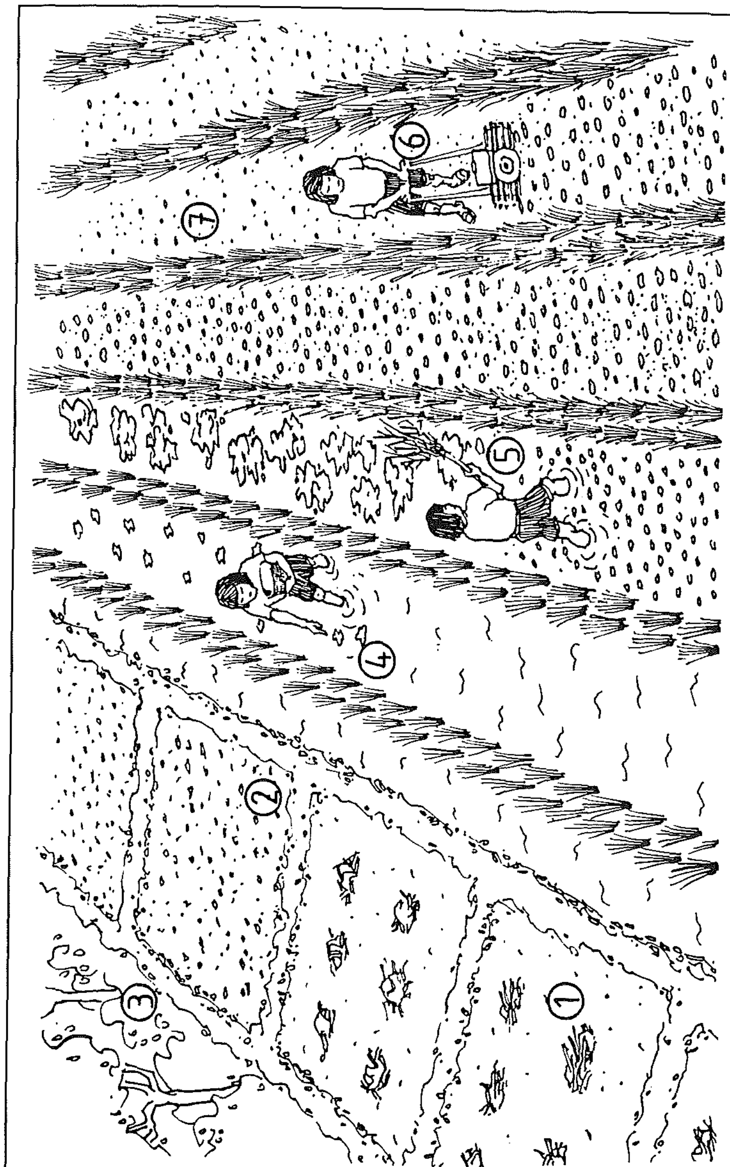
Treatment	1	2	3	4	5
	Azolla yield (kg/ha)				
After 10 days, before incorporation	-	13.7	12.4	8.8	12.4
After incorporation	-	-	-	4.1	2.9
After 20 days, before incorporation	-	24.5	21.5	15.8	13.8
After incorporation	-	-	-	-	6.5
After 25 days	-	22.9	-	20.4	10.9
After 30 days	-	1.9	-	-	13.8
Total yield	-	24.5	21.5	21.4	30.6
Paddy yield (t/ha)	3.7	4.4	4.4	5.0	5.0

1 No Azolla (control)
2 Natural decomposition
3 Incorporation of Azolla after 20 days (once)*
4 Incorporation of Azolla after 10 and 25 days (twice)
5 Incorporation of Azolla after 10, 20 and 30 days (three times)

* 2.98 t/ha of parent Azolla was applied on the day the rice was planted out

Source: CHEKIANG (1964), cited in CHU (1979)

Figure 4.4 Using Azolla in wetland rice: the double row method



1: Seedbed with compost applied; 2: Flooded seedbed; 3; Partially shaded seedbed; 4: Inoculation of the rice field with *Azolla*; 5: Beating (loosening) of *Azolla*; 6: Incorporation (also done manually); 7: Beginning of the new cycle.

Varieties with longer times to maturity make better use of the nitrogen released through the decomposition of Azolla than do those with shorter growing periods. In this method, the Azolla remains floating on the surface of the water until the end of the growing period. Large-scale trials involving double cropping were carried out using this method in China in 1976 and 1977, when 10.2 and 13.2 t of rice per ha per year were harvested respectively.

Table 4.14. Azolla yields (fresh matter) from *Azolla pinnata,* India

	In fields:			**In tanks:**		
	Inoculum	Total yield	Incre-ment	Inoculum	Total yield	Incre-ment
Mean monthly yield (t/ha)	13.6	41.6	28.0	11.8	35.5	23.7
Annual yield (t/ha)	164	498	334	141	462	321
Annual N yield (kg/ha)	410	1250	840	350	1150	800
Source: SINGH (1979), cited in HAMDI (1982)						

The Azolla yield was 112-149 t of fresh matter/ha (assuming a dry matter content of 3.5%, this represents 4-5 t DM/ha with a C/N ratio of approximately 10:1). An average of 224 to 300 kg/ha of nitrogen was gained (losses not calculated). Removing the Azolla for the green manuring of other fields is possible to some extent with this method.

In Brazil, 50-60 kg of N/ha was accumulated in 6 weeks using *A.filiculoides* as a catch crop, a quantity capable of meeting the nitrogen requirements for a 4000 kg/ha rice harvest. Through repeated incorporation (involving high labor costs), yields of up to

7 t/ha were achieved by undersowing Azolla. *A.pinnata* fixed up to 3 kg of N/ha per day. In 60 days, 100 kg N/ha were accumulated at temperatures ranging from 16° to 20°C. For a good Azolla harvest preceding rice, a period of 6 to 10 weeks was necessary under the conditions prevailing in Brazil (GUTBROD, 1982).

In California, *A.filiculoides* produced 1700 kg DM or 52 kg N/ha in 35 days, starting from an inoculation quantity of 50 g/m^2. This represents a fertilizer value of about 40 kg of mineral nitrogen (NH^+_4) (assuming 25% N loss). Table 4.14 shows the results of trials in India, in which Azolla was cultivated once only.

Table 4.15. Average chemical composition of *Azolla pinnata*

Component	% (dry weight)*
Ash	10.5
Crude fat	3.0-3.4
Crude protein	24-30
Nitrogen	4-5
Phosphorus	0.5-0.9
Calcium	0.4-1.0
Potassium	2.0-4.5
Magnesium	0.50-0.65
Manganese	0.11-0.16
Iron	0.06-0.26
Soluble carbohydrates	3.5
Fibrous material	9.1
Starches	6.54
Chlorophyll	0.34-0.55

* Dry weight is about 3-4% of fresh weight
Source: SINGH and SUBUDHI (1978) cited in HAMDI (1982)

Some possible additional benefits of growing Azolla in association with rice are weed suppression, the supply of green manure for other crops, the production of composting material, the utilization of spare labor, water or space and, as GUTBROD (1982) points out, the improvement of phosphorus availability for wetland rice. Another possible use for Azolla, widespread in China, is as livestock fodder. It is especially common as an ingredient in pig feed. Fed to animals in a dry state, Azolla may account for up to 50% of the ration. Its feed value is analyzed in Table 4.15.

HAMDI (1982) asserts that, under good growing conditions, a 100 m^2 cultivation area will suffice for feeding two pigs. Dried Azolla can replace 25-30% of the commercial chicken feed given to laying hens. GUTBROD (1982) also mentions the suitability of Azolla as fish food.

4.9 Green manuring with leaves

According to KARUNAIRANJAN (1980), green manuring with leaves (or green-leaf manuring) involves "collecting green plant materials and applying these as organic fertilizer". This method is common in many places as a supplement to other organic fertilizer application practices. Green-leaf manuring is especially useful in areas where the cultivation of green manure plants would place too great a strain on the water budget, depriving the main crop of adequate supplies, or where the time is too short to grow a green manure crop. In India, therefore, this method is recommended for semi-arid locations (MINISTRY OF AGRICULTURE 1975).

In India and China, green-leaf manure is frequently applied to intensively cultivated soils in rice-based systems. This permits the near continuous cultivation of these valuable fields for valuable cash crops, as well as rice, with the biomass necessary to maintain their fertility being brought in from other fields. In this way, nutrients from marginal land which is useless for arable farming are concentrated on intensively cultivated land.

The benefits of green-leaf manuring were established through a number of studies in India (REHM and ESPIG 1976). The positive effects were shown to lie specifically in a nutrient effect and in a short-term improvement in soil structure. Besides herbaceous green manure plants, tree and shrub legumes such as *Gliricidia sepium, Sesbania grandiflora* and *Butea monosperma* play an important role in this practice. In Java, *Sesbania* (grown on the embankments around rice fields) supplies 55 t/ha or more of fresh matter over 6-7 months.

In Sri Lanka, trees and perennial bushes are commonly used for green manuring. From October to November, shortly before the first monsoon rains, farmers cut back the trees and bushes along paths, on slopes and in hedges and carry the green material to their fields with ox-carts or by hand. There, using simple tools (hoes), they bury the fresh matter 30 cm deep in the soil. Algae and water plants plucked from ponds are also used in this way (KARUNAIRANJAN 1980).

On the island of Ukara in Lake Victoria, the inhabitants cut leaves from two-thirds of the 60 species of tree and shrub that occur there to use as fodder or green-leaf manure (LUDWIG 1967). In Nigeria, the leaves from *Anthonotha macrophylla* are used extensively in the preparation of stable manure and as green manure (OBI and TULEY 1973, cited in OKIGBO 1977). Cuttings from the branches of legumes that sprout readily are used for hedgerows (garden enclosures, etc) and provide fodder, green manure and compost material (*Baphia nitida, Gliricidia sepium, Albizia* sp., *Pterocarpus* spp., *Milletia* spp.).

In the permanently humid rainforest of Yurimaguas in Peru, the applicability of a "high external input strategy" was tested through experiments on an Ultisol (SANCHEZ et al. 1982). At the same time, the effects of grass and leguminous green material were also examined. Eight t/ha of fresh leaves from *Pueraria phaseoloides,* found in surrounding tree plantations, were applied to crops. The yield level was 90% of that achieved in treatments with mineral fertilizers, in which, in addition to primary nutrients, lime and trace nutrients were also applied (see Chapter 5, Table 5.19). The nutrient content of 8 t of *Pueraria* consists on average of 45 kg N, 3 kg P and 30 kg K, whereas an application of mineral fertilizer supplies 40 kg N, 25 kg P and 90 kg K. Without tree crops, agriculture would be impossible in the evergreen tropical forest. Producing green material in tree plantations (*hevea*, palms, etc) therefore does not compete with arable farming - i.e. no sacrifice of land use is involved. The ground cover plants protecting the soil under these plantations constitute a secondary source of green material.

Besides the biological addition of nitrogen to the soil, another advantage of green-leaf manuring is the greater effectiveness of P and K fertilizer when applied in plant form, at least at this site. Moreover, the removal of nutrients through the leaves can be compensated more effectively in a plantation, where the trees cover more of the area and develop a more extensive root network than in a mixed tree-crop (agroforestry) system.

Table 4.16. Rice yields (t/ha) in green manure trials in Cambodia, 1958-1960

Fertilizer treatment	1958 First harvest	1958 Second harvest	1959 Average	1960 Average
a) Control	1.07	1.09	1.53	0.98
b) *Eupatorium* (20t/ha FM)[1)3)]	2.76	1.08[2)]	2.71	1.89
c) 60/30/30 NPK	1.73	0.99	-	
d) b + c	3.40	1.45	-	

[1)] 20 t green material contained approximately 110 kg N, 12 kg P_2O_5, 87 kg K_2O; [2)] Note that the green-leaf manure had no effect on the 2nd rice crop; fertilizer was always applied at the 1st crop period; [3)] Plowed in to a depth of 15 cm.

Source: LITZENBERGER and HO (1961)

In Cambodia, excellent results were achieved by green manuring with leaf material brought in from surrounding areas and applied to the rice fields (Table 4.16). *Eupatorium odoratum* (Compositae) is a dreaded weed in many parts of Asia. Since it must be cut back and controlled in any case, and since it grows abundantly along paths and in fallow areas, its utilization as a green manure entails little extra cost or effort. Indeed, using this weed as a green manure often renders weed control more economic. However, the advantages of green-leaf manuring mentioned above - the saving of time, greater flexibility, better use of soil moisture, more intensive use (integration) of marginal land, utilization of tree and shrub crops, etc - are offset by some disadvantages. More labor is required for transporting the green material. Because the leaves originate outside the cropping area the topsoil is not loosened by the root systems of the green manure plants, and fewer nutrients are mobilized from the subsoil. In other words, the overall benefits derived from a massive network of roots are lost.

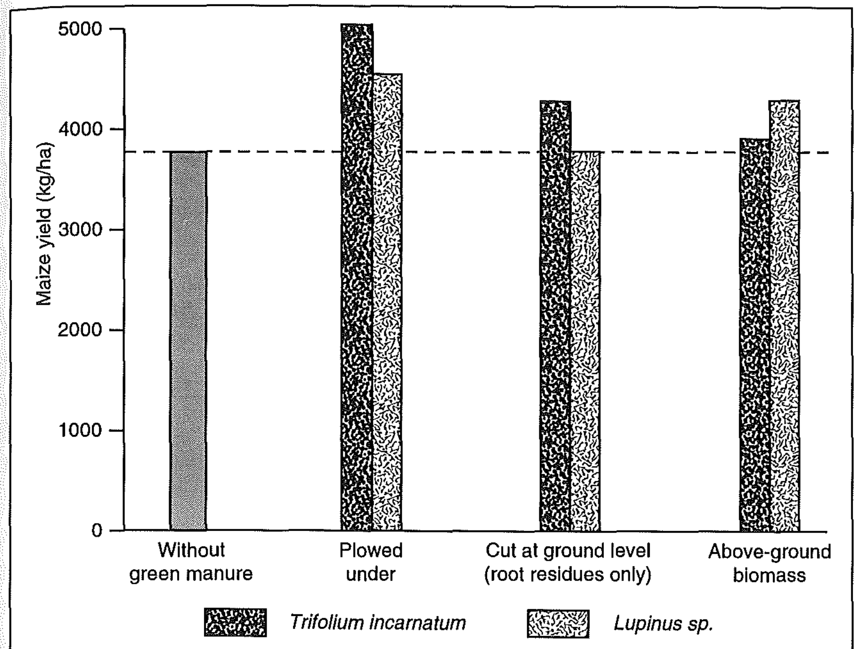
4.10 "Green" manuring with roots and stubble

Many authors point out that green manuring is only effective in some locations. HOWARD (1943) suggests that the fertilizing effects of roots and green material be separated on problem sites. For example, green material should be composted with straw or used as fodder to produce stable manure, while roots are left in the soil.

The direct benefits of "green" manuring with roots depend primarily on the quantity of root material remaining in the soil after harvest. Early studies in Europe indicated that the species also plays a role here, since different green manure plants retain different nutrient contents in their roots (see Figure 4.5). While the green manuring effect of *Trifolium incarnatum* is chiefly due to its root residues, the reverse is true of *Lupinus* sp., whose above-ground biomass is more important.

According to BAUR (1949), on European farms 50-70% of the green manuring effect may be expected from leaving just the stubble for direct incorporation. He therefore recommends that the above-ground biomass be used as fodder for cattle. There are few data from the tropics on this point. Yet it is precisely in this part of the world, where the breakdown of humus is so rapid after tilling, that such a practice might be of greatest benefit because it requires less soil tillage.

Figure 4.5. Effects of various parts of green manure plants on maize yield using *Trifolium incarnatum* and *Lupinus* sp.



Source: BERKNER (1936), cited in BOGUSLAWSKI (1981)

Trials carried out over several years in India showed that, on average, the stubble and the herbage (stems and leaves) of *Crotalaria* each had a green manuring effect on sugar cane of 50%, and that these proportions were almost summed when the entire plant was incorporated (Table 4.17).

Trials testing the effect of stubble left on multi-seasonal intensive fallows in the tropical mountain region of Rwanda produced similar results, which raised the question of whether it would not be better to use at least a part of the above-ground biomass for compost or fodder (NEUMANN; personal communication).

Table 4.17. Effect of different plant parts of *Crotalaria juncea* on sugar cane yield (kg/ha)

Treatment	1953-54	1954-55	1955-56	1956-57	Average	(%)
	---- Year ----					
No green manure (fallow)	317	265	124	176	221	100
Herbage (plowed in)	382	350	141	188	265	120
Stubble (plowed in)	348	351	153	213	267	121
Whole plant (plowed in)	415	383	194	241	308	140

Source: SINGH (1975)

Table 4.18. Nitrogen fixation by grain, fodder and green manure legumes (kg/ha/year)

	Average	Range	Author
Pulses			
Phaseolus aureus (mung beans, green)	202	63-342	NUTMAN(1976)
Phaseolus aureus	61		cited in HAMDI (1982)
Cajanus cajan (pigeonpea)	168	96-280	cited in HAMDI (1982)
Vigna unguiculata (cowpea)	198	73-354	cited in HAMDI (1982)
Canavalia ensiformis (Jack bean)	49		cited in HAMDI (1982)
Cicer arietinum (chickpea)	103		cited in HAMDI (1982)
Arachis hypogaea (groundnut)	120	72-124	cited in HAMDI (1982)
Calopogonium mucunoides	202	170-450	cited in HAMDI (1982)
Glycine max (soybean)	70	64-206	AYANABA and DART (1977)

Table 4.18 continued. Nitrogen fixation by grain, fodder and green manure legumes (kg/ha/year)

	Average	Range	Author
Fodder and green manure legumes			
Centrosema pubescens (alone)	271	126-395	AYANABA and DART (1977)
Centrosema pubescens (in combination with *P.purpureum*)	123		WHITNEY cited in HAMDI (1982)
Desmodium intortum (alone)	406		WHITNEY cited in HAMDI (1982)
Desmodium intortum (in combination with *P.purpureum*)	378		WHITNEY cited in HAMDI (1982)
Desmodium canum (alone)	94		WHITNEY cited in HAMDI (1982)
Desmodium canum (in combination with *P.purpureum*)	136		WHITNEY cited in HAMDI (1982)
Leucaena leucocephala	277	74-548	NUTMAN (1976)
Sesbania cannabina	442		NUTMAN (1976)
Pueraria phaseoloides (tropical kudzu)	99		NUTMAN (1976)
Stylosanthes (sp.)	124	100-200	TALINEAU et al. (1976)
Azolla pinnata (per year)	800	600-1000	HAMDI (1982)

4.11 Effects on soil

4.11.1 Effects on the nutrient and humus economy

The short-term productivity gains from green manuring or intensive fallowing are due in the first instance to an improvement in the supply of nutritive elements to the crop plant. Many plants used for these purposes have an extremely high capacity for assimilating nutrients from the soil; these become available to the following crop as soon their organic matter is mineralized. In soils with normal decomposition conditions, this process results in an evenly flowing source of nutrients (PIETROWICZ and NEUMANN 1987).

Nitrogen. The most significant effect of legume cultivation on the nutrient economy of the soil is nitrogen enrichment. Nitrogen fixation values may be high or low depending on the growing conditions. Experiments have shown that legumes grown under good nutrient conditions fix considerably more nitrogen than they do on a deficient site (Table 4.19, see also Section 8). Perennial plants retain the ability to fix nitrogen after flowering.

Table 4.19. Nitrogen fixation by legumes (kg/ha) under optimal and suboptimal nutrient supply conditions*

Leguminosae	Number of weeks before flowering **	Unfertilized soil, no inoculum	Soil with N-free nutrient solution and inoculum
Phaseolus aureus	7	63 (100)	224 (355)
Vigna unguiculata	12	157 (100)	354 (225)
Calopogonium mucunoides	14	370 (100)	450 (122)

* Greenhouse trial in pots, ** Time of optimal nitrogen fixation

Source: AGBOOLA and FAYEMI (1972a)

If the next crop is to make good use of the nitrogen from legumes, the soil should possess good conditions for the cultivation of green manure and for the growth of the main crop, as nitrogen availability depends greatly on the conditions following incorporation.

Trials by WEERARATNA (1979) showed that the mineralization of green material is more efficient under aerobic (59% field capacity) than under anaerobic (waterlogged) conditions (Table 4.20).

Table 4.20. Total available NH_4^+ and NO_3^- nitrogen content of the soil after mixing with organic matter under aerobic and anaerobic conditions (mg/100 g)*

Treatment	Incubation period (weeks)							
	0	1	2	3	4	5	6	7
Aerobic conditions:								
Soil	10.3	18.0	20.9	21.7	20.7	24.3	25.1	25.8
Soil + *Gliricidia*	10.3	23.2	26.8	29.3	30.4	32.1	33.1	34.1
Soil + sunflowers	10.3	19.2	21.4	22.0	22.4	21.7	23.2	24.0
Soil + *Centrosema*	10.3	26.3	33.0	43.0	45.8	47.6	48.4	48.9
Soil + *Calopogonium*	10.3	24.5	29.9	36.0	37.6	38.8	39.8	42.1
Soil + *Crotalaria*	10.3	23.8	25.9	28.3	30.7	34.6	37.0	40.1
GM 5%	-	2.7	2.4	2.5	2.2	2.4	2.6	2.5
Anaerobic conditions:								
Soil	10.3	14.8	15.4	15.4	16.3	17.1	17.3	18.2
Soil + *Gliricidia*	10.3	16.1	17.2	17.9	19.4	19.9	20.2	21.4
Soil + sunflowers	10.3	15.9	17.4	17.4	17.7	17.7	18.1	19.0
Soil + *Centrosema*	10.3	16.7	17.6	18.4	18.8	19.5	20.0	21.2
Soil + *Calopogonium*	10.3	15.0	16.1	17.3	17.8	18.8	20.6	20.9
Soil + *Crotalaria*	10.3	16.5	18.1	20.2	20.5	21.1	21.9	22.3
GM 5%	-	2.1	2.5	2.6	2.9	2.6	2.8	2.9

* Addition of 1 g ground green manure material per 20 g of soil; organic content of the trial soil: 1.86%; pH:6.4; total nitrogen content: 0.18%.

Source: WEERARATNA (1979)

The process of mineralization was slow under anaerobic conditions, and the amount of available soil nitrogen (also influenced by denitrification) was less at all times. These results support the theory that loose, porous soils are better suited for green manuring than heavy soils with poor drainage.

The question raised by these trials is how much of the nitrogen fixed by legumes actually is or could be utilized by the main crop. Besides soil conditions, which are the main determinant, the species of plants involved (green manure/intensive fallow and main crop) have an important influence on this. The degree to which nitrogen is utilized also depends on whether the supply (through mineralization) and demand (peak demand of the main crop) coincide in time. According to KLAPP (1967), this can vary from 12 to 50% in the case of legume-derived nitrogen. KAHNT (1983) reports 20-60% (80% in extreme cases). In trials by AGBOOLA and FAYEMI (1972a), the nitrogen effect of *Calopogonium* and *Vigna* on the following maize crop was about 45 kg N/ha, or 12-30% utilization. Utilization levels of 54 to 76% were recorded for green manuring with *Azolla* on rice (HAMDI 1982).

Because nitrogen mineralization often takes place before the demand for nitrogen by the following crop reaches its peak, considerable loss of nitrogen frequently occurs with green manuring. In this connection, VALLIS and JONES (cited in WHITNEY 1982) made the interesting observation that the lapse of time for nitrogen liberation does not depend only on the nitrogen content of the plants, but that accompanying elements in the plant tissues can also play an important role. For example, when leaves from *Desmodium tortuosum* were turned into the soil, 24% of the nitrogen from them was shown to be present in the subsequent crop of Rhodes grass just 6 weeks later. This was not the case with *Desmodium intortum*. With this subspecies there was no sign of nitrogen mineralization whatsoever in the first 4 weeks - the first stages of mineralization were extremely slow and halting. Only after 4 weeks did mineralization get under way, then progressing similarly to *D.tortuosum*. *D.intortum* proved to have a high content of tannin-bound proteins. Thus it provides a kind of "slow-release" - or better - "retarded-release" nitrogen. Provided that the tannin-bound proteins do not hinder the growth of the subsequent crop, this can be quite an advantage, as it may delay the full availability of nitrogen so that this coincides with the peak demand of the following crop.

Green material is rich in nutrients and energy and, as a consequence, stimulates soil life. This in turn promotes the release of the soil's own nitrogen from humus. LOHNIS described this relationship as early as 1926, and BROADBENT and NORMAN (cited in JAISWAL et al. 1971) confirmed it experimentally with labelled

nitrogen in 1947. Green manure can thus make available and mobilize significant quantities of nitrogen (see below). However, the effect usually lasts for only one or two growing periods. A long-term, lasting improvement in the nitrogen status of a soil cannot, as a rule, be expected from green manuring.

In 2-year studies with legumes undersown on a sandy Ultisol in Nigeria, AGBOOLA et al. (1975) were able to determine that the breakdown of nitrogen in soil with green manure was 2-2.5% per year and hence not significantly different from the control.[78] With additional mineral fertilizer, the yearly losses climbed to 4.7-5%. According to experiences in India (JAISWAL et al. 1971), the permanent soil humus (humus-nitrogen) is especially prone to breaking down when small amounts of green manure, in an easily decomposable state, are incorporated. This accelerates mineralization, with little humification.

The organic matter in multi-seasonal intensive fallows, on the other hand, does not decompose at all readily. Furthermore, greater quantities of biomass are produced. It can therefore be assumed that, for long-term effectiveness, this is the better method. For example, according to JUO and LAL (1977; cited in RAMAKRISHNAN and TOKY 1981), in West Nigeria, 16 t DM/ha per year of organic matter were required to maintain the carbon status of a field at the same level as a secondary forest. As the example of Nyabisindu, Rwanda (see Section 4.6) has shown, these values are very nearly reached when an intensive bush fallow component is included in the rotation - though only once every 4 years.

Humus status. In principle, data on the nitrogen content of a soil are also a measure of its humus content: if the C/N ratio of the organic matter is more or less constant, the supply of nitrogen in the soil depends directly on the amount of organic matter present.

Table 4.21 shows the results of a long-running soil fertility trial begun in India in 1908. Green manuring did not bring about any large increase in the humus content of the soil, but had an overall positive influence. Mineral fertilizer applications had a

[78] If it is assumed that the top 20 cm of soil, with 2% humus, is involved here, this represents a nitrogen mobilization of approximately 50-70 kg/ha per year.

more positive effect here than at the more humid site at Ibadan, Nigeria, where they clearly accelerated carbon decomposition.

Table 4.21. Carbon content of soils (%) in a long-running soil fertility trial in Pusa, India

Treatment	Period			
	1940-41	1947-48	1954-55	1957-58
Control	0.223	0.212	0.229	0.280
N-P-K	0.235	0.292	0.245	0.365
Green manure	0.228	0.291	0.257	0.358
Green manure + P_2O_5	0.300	0.315	0.261	0.430

Source: Adapted from SINGH (1967), cited in JAISWAL et al. (1971)

Table 4.22. Trends in soil characteristics in a crop rotation trial over many years, with 30-50% legume fallow (1960-70) and without legume fallow (1971-76), Bouaké, Côte d'Ivoire*

Year	Clay content (%)	Organic matter (%)	C/N ratio	Base saturation (m.e./100g)	pH
1960	18.5	2.6	12.6	7.7	6.2
1969	18.5	2.9	11.5	8.4	6.6
1976	18.1	2.6	17.7	3.1	4.7

* Savanna; rainfall 1200 mm/year, coarse sandy soils; mineral fertilizer contained about 18, 20 and 27 kg/ha of N, P and K respectively plus top dressing (20-60 kg/ha N) depending on crop. After 1970, nitrogen fertilizer was increased to 50-60 kg/ha, to compensate for the absence of legumes.

Source: BUANEC and JACOB (1981)

In Côte d'Ivoire, long-term crop rotation trials were conducted that included 1- to 2-year intensive fallows with legumes during the first 10 years. The effect of these fallows was highly positive (Table 4.22).

The trials showed that while green manuring with legumes (*Stylosanthes* sp. and *Desmodium* sp.) on the moist savanna site did not bring about a radical improvement in soil conditions, it was able to maintain or even somewhat improve the fertility level of the soil over 10 years, with only a little additional mineral fertilizer. On the other hand, when rotation with legumes was abandoned, the humus quality deteriorated within only 6 years. This resulted in reduced base saturation, the erosion of fine particles and soil acidification.[79]

KAHNT (1983) pointed out that in temperate climates, green manuring combined with reduced or minimal tillage can contribute to humus enrichment whereas, with intensive tillage, a humus-consuming effect is possible. In the tropics it is also likely that minimizing soil tillage will promote the process of increasing and building humus.

In conclusion, although green manuring improves nitrogen nutrition, a significant enrichment of humus in the tropics is unlikely because of the rapid mineralization of fresh matter and the effect of this on soil life. Thus green manure differs from other forms of organic fertilizers (stable manure and compost) which, in addition to their nutritive effects, also benefit the humus status. This was reaffirmed by GUIRAUD et al. (1980) in pot trials with green material, straw and compost. In this respect multi-seasonal intensive fallowing and regular undersowing are more effective than green manuring (see Sections 4.6 and 4.7).

Phosphorus availability. In the literature it is often reported that the soil phosphorus available to plants is improved by growing legumes (e.g. KAHNT 1983). On a site in Nigeria, a single season intensive fallow with *Crotalaria* spp. succeeded in increasing the available P content of a field soil from 7.8 kg/ha to 12.1 kg/ha (AGBOOLA 1975). In another experiment, undersowing legumes in maize reduced the uptake of available phosphorus by some 50% within four growing seasons.

[79] The acidifying effect came partly from the mineral fertilizers and partly from the non-restoration of bases from the subsoil via the legumes.

AGBOOLA and FAYEMI (1972b) concluded that the legumes were able to keep the phosphorus in an available state, protecting it from mineral fixation.

SÖCHTIG (cited in FLAIG et al. 1978) pursued this question in laboratory experiments. He observed that the amount of extractive phosphorus in a lateritic soil was higher after applications of an organic N fertilizer than when phosphate alone was applied. After 4 weeks the differences had disappeared, but availability increased again in response to further applications of organic N compounds. According to BOYLE et al. (cited in FLAIG et al. 1978) it is the organic acids released through the decomposition of organic matter that mainly contribute to the increased availability of phosphorus. Bivalent and tervalent acids, such as citric, hydroxysuccinic and oxalic acid, proved especially effective. In addition, legumes release H^+ ions into the rhizosphere. This aids the solubility of phosphates.

On the other hand, the legumes' high demand for phosphorus and their sometimes marked capacity to assimilate it can result in a temporary, biological fixation of phosphorus, especially on soils with very low phosphorus availability. PIETROWICZ and NEUMANN (1987) observed this in the first following crop on individual trial plots in Nyabisindu, Rwanda. The effect disappeared by the time the second following crop was grown. Moreover, the authors assumed that this blocking of phosphorus does not occur, or does so only slightly, when the roots of the crop plants associate early with mycorrhizae, the hyphae of which grow directly into the incorporated biomass.

Besides these soil chemical factors, it must not be forgotten that green manuring or intensive fallowing also improves the extension and formation of roots in the soil. This too enhances the overall capacity of the plants to assimilate phosphorus. This effect is due to the dissolution of other soil nutrients such as K, Mg, trace elements, etc.

The solubility of metallic trace elements is improved through green manuring (through complex and chelate formation). The solubility of iron and manganese can increase sharply as a result of the decomposition of fresh organic matter under anaerobic conditions. On iron-rich soils this could, under some circumstances, lead to toxicity (FLAIG et al. 1978).

In India, green manuring is used to improve saline soils. The chief benefits are the uptake of water from deeper soil strata, the reduction of evaporation, and improved solubility of phosphorus and trace elements. *Sesbania bispinosa* has proved suitable for saline, alkaline soils (JAISWAL et al. 1971).

4.11.2 Effect on soil structure

Green manuring and intensive fallowing are primarily biological methods of soil maintenance. They are distinct from mechanical methods such as rotary tilling, hoeing, deep plowing, etc. Mechanical cultivation can only break up the soil (thus rendering it more prone to erosion); it cannot create a natural, stable aggregate. This can only be developed through biological or chemical means (KAHNT 1983), or through physical processes such as expansion and contraction.

Root space and pore volume. Of the various methods discussed here, intensive fallowing is the one that most thoroughly permeates the soil with roots and pores, and is able to loosen, break up and process the soil (the longer the fallow period, the more pervasive the effect). Intensive fallowing produces a crumb structure which facilitates soil cultivation and the root growth of crop plants. The deeper and more easily a soil can be penetrated by roots, the more the crop plants are able to take up, assimilate and utilize water and nutrients (SAUERLANDT 1948).

This was demonstrated in the green manure trials with *Dolichos lablab* by RODRIGUEZ (1972) (see Table 4.4). Yields of maize in the second season, which is characterized by unreliable rainfall, were higher when the crop was rotated with deep-rooting legumes than when other treatments were applied. The reason was probably that the maize roots were able to extend through a larger volume of soil, which improved the water supply.

The same phenomenon was observed by PIETROWICZ and NEUMANN (1987) in their experiments in Nyabisindu, Rwanda. An annual intensive fallow (see Section 4.7) increased the soil depth penetrated by the roots of subsequent food crops. "This was particularly apparent on shallow soils over granite and on soils where the depth of the topsoil was limited by a compacted horizon. At first it was impossible to till the stony soil by hoeing, and the maize sown failed to yield. One small section of the field was broken up with a pick, but even this extremely laborious method did not produce any notable improvement. The maize roots were entirely confined to the upper, loose centimeters of soil. The plants sown here extended their root systems 2 meters deep in 18 months. The soil could then be worked with a hoe to a depth of about 10 cm, and maize was successfully grown over one season. A second 10-month (intensive) fallow period increased the depth of workable soil still further, permitting the harvest of over 2000 kg/ha of maize grain. Everything seemed to indicate that this level of yield could be maintained."

Extensive trials by KEMPER and DERPSCH (1981), in the (subtropical) state of Paraná in Brazil, clearly demonstrated the effects of increased root extension and biological activity on the infiltration rate of a soil which was severely compacted due to mechanical cultivation (Table 4.23). Mechanical cultivation of this originally good porous soil produced only short-term effects. Crop rotation with ground cover plants, minimum tillage and the application of mulch appreciably upgraded the soil.

Table 4.23. Infiltration rates on two cultivated soils under different crops in Paraná, Brazil

Infiltration (mm/h)	Wheat	Rape	Russian vetch	Turnip	Lupine	Phacelia
Site A*	44	79	87	103	125	183
Site B**	64	303	402	-	-	-

* Haplorthox (Latosol), ** Rhodic Paleustalf (Terra Roxa)

Source: KEMPER and DERPSCH (1981)

Aggregate stability. Green manuring carries out a further important function in promoting the formation of soil particles near the soil surface. While growing, the shade green manure crops provide protects soil life. Incorporation encourages a rapid

increase in biological activity. Fungal hyphae and excretions from soil organisms (mucin and mucilage) promote the formation of crumbs and of a stable aggregate structure (KULLMANN 1966; WENDT and STARK 1968; YAACOB and BLAIR 1981).

In pot trials, YAACOB and BLAIR (1981) examined the effect of growing soybean and siratro (*Macroptilium atropurpureum*). By increasing the number of times these were grown, they achieved a rapid and steady improvement in aggregate formation and infiltration (Table 4.24).

Table 4.24. Effects of growing one to six legume crops on infiltration rate and the formation of a water-stable soil aggregate*

Number of times legumes cultivated	Stable aggregate (%)	Infiltration rate (mm/min) Time interval 0-15 min.	10-15 min.
1 x Soybean	39.4	8.1	1.1
1 x Siratro	47.3	4.1	1.8
3 x Soybean	58.9	12.3	1.2
3 x Siratro	57.5	10.6	1.9
6 x Soybean	77.1	13.4	1.7
6 x Siratro	61.6	15.4	1.3

* Pot experiments

Source: YAACOB and BLAIR (1981)

In pot experiments by MILLER and KEMPER (1962) it was found that, after lucerne had been incorporated, the proportion of water-stable aggregates steadily increased by over 100% throughout the rest of the trial period (9 weeks). The temperature during the trial was a constant 25°C. At 35°C, the increase in stable aggregates ceased after only 4 weeks, and after 9 weeks the proportion of stable aggregate was slightly lower than in the control, because the decomposition of stable humus had been stimulated. YAACOB and BLAIR (1981) stress that under warm, moist conditions, a sustainable improvement in soil fertility can be expected only if the soil is supplied with organic matter frequently and regularly.[80] Experiments by GLIEMEROTH (1958) showed that this conclusion is also valid in temperate climates. In addition, all three authors concluded that frequent and intensive tillage has an inhibiting effect on the formation of a stable crumb structure and reduces the long-term effectiveness of organic fertilizers.

Another way of promoting good tilth is to combine different materials. In trials by CHARREAU (1975) on sandy loams, various plant residues of different lengths were found to influence soil structure. Straw had the most long-lasting effects (measured 1 year after incorporation), followed by compost, root material and green material. By combining nitrogen-rich green material with lignin-rich straw (by undersowing in a grain crop), an intermediate effect can be created that stops short of fixing nitrogen.

A final point is that the improvement in soil physical characteristics frequently derived from green manuring greatly depends on the location. Thus LUGO-LOPEZ et al. (1978) achieved excellent results on an Ultisol, whereas the improvement on an Oxisol was negligible. JAISWAL et al.(1971) reported experiments on sandy alluvial soils in India in which the soil physical properties were only slightly improved by 50 years of regular green manuring. However, alternating or combining stable manure or straw on sites that had failed to respond to green manure alone usually produced a marked improvement.

To sum up, by including a green manure or an intensive fallow in the rotation, the physical characteristics of a soil can be improved relatively quickly. However, the effects, at least in the topsoil, also subside quickly. Indeed, the higher the soil temperature the more rapid the decline.

[80] After 5-9 weeks, most stands of annual crop plants are closed, so the soil is protected from the effects of violent downpours.

4.11.3 Phytosanitary effects

Soil-borne diseases. The incorporation of green manure and crop residues induces radical changes in soil life. Soil-borne pathogens and their associated diseases may be reduced. ALLISON (1973) mentions wart disease of potatoes, blackleg in grain, *Phymatotrichum* soft rot in cotton, and *Rhizoctonia solani* and *Fusarium solani* in beans as examples. Three mechanisms are primarily responsible:

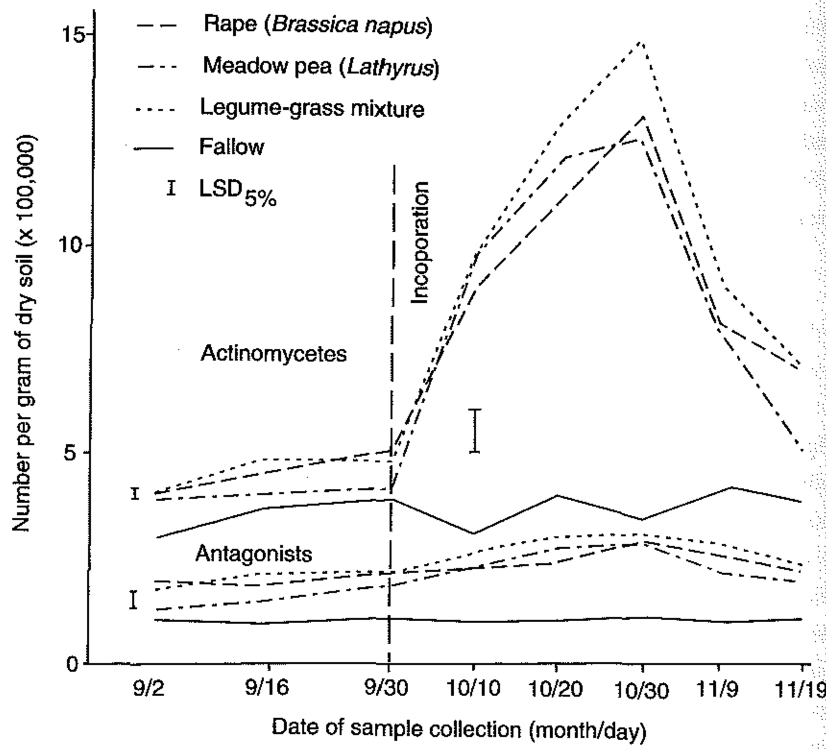
* direct influence on parasitic activity;
* influence on parasitic survival rate;
* indirect effect through improved resistance of the host plant.

According to studies by LINDERMAN (1970), the decomposition of green manure often triggers the growth of pathogenic fungal spores and bacterial carriers. When this occurs before a suitable host is present and the hyphae that have developed undergo lysis, a pathogen can be effectively checked. This has been demonstrated with *Fusarium oxisporum*. However, the increase in bacterial soil life may also hinder the germination of sclerotia. If sclerotia nevertheless manage to germinate, they are vulnerable to attack by enemies and parasites. Figure 4.6 shows the reaction of direct antagonists and of soil organisms in general (in this case the actinomycetes) to green manuring as opposed to fallow.

KAHNT (1983) cites experiments in which it was demonstrated that nematode-catching fungi could be multiplied significantly through green manuring. Nematodes can also be combated directly by growing plants hostile to them in the intensive fallow (*Tagetes* sp., *Eupatorium* sp., lucerne). In experiments by IITA (1977) in Nigeria, *Pueraria phaseoloides* and *Stylosanthes gracilis* proved highly effective against nematodes.

When growing a short-term catch crop, cyst-forming nematodes can be combated by sowing varieties typically prone to nematodes. These are then eradicated after infestation but before the cysts are formed, so that the nematodes die off, being unable to complete their development cycle.

Figure 4.6. Influence of green manure on the number of actinomycetes and antagonists against *Ophiobolus graminis* (blackleg)



Source: EHLE, in KAHNT (1983)

According to REINMUTH (1968), green manuring generally strengthens the "antiphytopathogenic potential" of cultivated soils, thus lessening the risk of losses. This does not, however, preclude possible exceptions. For instance, LINDERMAN (1970) mentions the susceptibility of tobacco to infestation by black root rot (*Thielaviopsis basicola*) after green manuring with *Vigna sinensis*. It is well known that some green manure legumes promote disease when rotated with beans.

In addition, the **weed flora** can be strongly influenced by intensive fallowing or green manuring. Seed-bearing weeds sprout up, but can be suppressed by dense, tall stands

and may then be incorporated into the soil with the biomass. Where the first growth is utilized for fodder, weeds and any seeds present are removed with the fodder crop. From Benin it was reported that intensive fallows with *Cajanus cajan* helped control *Imperata cylindrica* (FLOQUET 1990). In Rwanda it proved possible to suppress grasses (*Agropyron, Digitaria* sp. and sometimes *Cynodon dactylon*) with an intensive fallow of persistent, tall perennials. Tall plants are able to block the sunlight for long periods, a deprivation to which light-demanding grasses and other weeds are sensitive. For this purpose an intensive fallow is superior to a natural fallow. According to NYE and GREENLAND (1960) and NYOKA (1982), the latter requires at least 5-10 years to overcome destructive weeds. The duration of a fallow is often governed by its weed controlling ability.

Careful observation of weeds and green manure is always advisable to ensure that more good than harm results from intervention. Choosing plants of suitable species and provenance, and combining this with selective weeding in the young stand (which is facilitated by row-planting) improves the chances of success.

4.12 Socio-economic aspects

Social and economic factors both within and beyond the farm greatly influence the appeal of green manuring and intensive fallowing to farmers. The application of green manure has the following advantages:

* It may increase yields, sometimes substantially;
* Soil physical (and, in some cases, chemical) properties can be improved markedly (infiltration, workability, water-holding capacity, ease of root extension);
* It enables a farmer to produce nitrogen and relatively large amounts of organic matter on site (for on-farm circulation);
* It does not generally involve costs or labor for transport;
* The maintenance (or increase) of fertility is based on the farm's own resources (and less capital is required).

There are, however, also factors which make the acceptance and application of green manuring difficult:

* The cultivation of single or multi-seasonal intensive fallows incurs a short-term economic loss, i.e. the income foregone from food crops that might have been grown instead. (This loss does not occur if the alternative would have been to simply leave the field fallow.)
* On rented land, long-term measures for maintaining soil fertility are often regarded as not worthwhile. Intensive fallowing may even be forbidden, as it can cast doubts on the tenure of the owner.
* Seed and planting costs are incurred.
* Acquiring enough seed of suitable quality is often a severe problem.
* For smallholder farms, incorporating biomass involves heavy manual labor.

For these reasons it is not easy to introduce green manuring or intensive fallowing where they are not already practised traditionally (OKIGBO 1977; OFORI 1980; DUNCAN 1975; ARAKERI et al. 1962; BURNETT 1975). These practices tend to be found only where, under rising population pressure, natural fallowing has become either impossible altogether or too short to be effective, and there is at the same time an urgent need to intensify the productivity of cropland, as, for example, on the island of Ukara in Lake Victoria (LUDWIG 1967) or in many parts of China.

Short-term costs. As mentioned above (RODRIGUEZ 1972), green manuring or intensive fallowing can be so effective in improving yields that the loss of income from one or two harvests is more than offset by the larger yields achieved thereafter. As a rule, however, a somewhat smaller response must be expected, at least in the short term. If the benefit of measures is not immediate, acceptance by farmers will be slower.

As demonstrated by the long-term trial in Zimbabwe (RATTRAY 1956, cited in WEBSTER and WILSON 1980) described above, a protracted period of time before

measures become effective must be expected. In this trial, it was only in the third cropping season that yields achieved a level that more than made up for the sacrifice of a maize crop. After green manuring for 22 years, the overall performance with green manure was 43% better than without it.

Measures bringing long-term benefits are difficult for farmers to put into practice. Farmers are often under pressure, from their families, if not from central government, to increase productivity now. Under these circumstances economic calculations, such as those of DRESSLER (1983) for smallholdings in Rwanda, make little impression. DRESSLER reported that under the prevailing conditions of high population pressure and scarce land, a rotation with an intensive fallow supplemented by compost represented the least expensive means for small farms (0.4-0.8 ha) to maintain soil fertility.

In India, advisory services have adopted the following strategy: green manuring is first introduced on only one-fifth of the farm area (if possible, without the loss of an entire main crop on this area). Then bit by bit, as the benefits of green manuring become apparent, the area under green manure is extended to a quarter and finally to a third of the cropland (MINISTRY OF AGRICULTURE 1975).

A further way of avoiding short-term sacrifices is to undersow a green manure simultaneously with the main crop. As the results of AGBOOLA and FAYEMI (1972a, 1972b) show, good results can be achieved if suitable varieties are chosen and site conditions are favorable, even using grain legumes (Table 4.7). However, the soil fertility effect with this method lags behind that of pure green manuring. The nitrogen left behind in the roots of grain legumes is only about 15% of that present in green manure with shoots (KAHNT 1983).

Another way of adding to the value of intensive fallows is to feed all or part of the biomass to livestock. This is traditionally practised in China (ALLISON 1973) and in many other countries.

In some situations there is little or no alternative to the continuous application of green manure, so that the economic analysis of alternatives is somewhat academic. Farmers in Rwanda use intensive fallows where land has become so degraded that agricultural production is no longer possible. A 1- or 2-year fallow helps the soil to recover, while at the same time supplying valuable firewood.

With regard to the problems of transport, green manuring is especially interesting for fields some distance from the home, as high transport costs are incurred in supplying them with fertilizer from elsewhere.

A farm can avoid high seed costs by producing seed from its own crops. According to von SCHAAFFHAUSEN (1963) this is possible with species such as *Dolichos lablab*, which are good seed producers. Some species produce little seed, however. In Malaysia, YEOH (1979) successfully managed the vegetative propagation of *Pueraria triloba* and *Calopogonium caerculeum* with fully developed scion cuttings, but this technique is too laborious for small-scale application. OKIGBO (1980) reported that farmers in Nigeria use cuttings for planting bush fallows.

Planting material is not the only input that can be scarce and expensive. Mineral fertilizers are as well. In Yurimaguas, Peru, green manuring with *Pueraria* proved economic for its nitrogen effect alone, as the cost of growing 1 kg of nitrogen in the form of *Pueraria* (cutting, collecting, planting, plowing under) was no higher than purchasing the nutrient (SANCHEZ and SALINAS 1981).

Finally, benefits such as reducing or preventing erosion should not be left out of the economic equation, as they frequently are. If we assume that, without green manuring, 2.5 cm of soil per hectare is lost each year, this incurs a loss of about 500 kg of nitrogen/ha/year (given a C content of 2%).

4.13 The zonal context

Both green manuring and intensive fallowing require a good water supply. Hence these methods are especially applicable in the humid and subhumid zones.

In the **permanently humid inner tropics**, on extremely poor soils, the chief concern is to keep nutrients in the biological cycle (just as nature does). The water supply is favorable for cropping year round, so that green manuring and intensive fallowing are relatively easy to integrate into the existing production system. Between cropping cycles, the soils can easily be covered with species such as *Dolichos lablab*, *Vigna* and *Phaseolus* spp. (REHM and ESPIG 1976). In this way, nutrients are stored and protected in the plants, and weeds can be kept down (NYOKA 1982). A considerable amount of organic material can be produced in only a few weeks, for plowing under before planting the new crop. However, under permanently humid conditions it is not yet certain whether it is better to turn the green material under or to leave it on the surface as mulch. ROOSE (1981) thinks it better not to bury the green material, but to rely on surface decomposition instead, and to avoid leaving the soil uncovered. Given the climatic conditions, decomposition on the surface (more than 90% through fungi and bacteria) is guaranteed. It is less certain where the soil is waterlogged and green material is plowed under.

In the **moist savanna**, two harvests per year are obtained. Here many plant species that suffer from disease pressure in the permanently humid zone find a niche. The selection of appropriate species and the integration of green manuring or intensive fallowing into the production system is determined by seasonal differences in water supply. For the main rainy season, undersowing is expedient, whereas the uncertain, shorter rainy season is suitable for seasonal rotation systems. Growing a catch crop can be problematic because of the limited water supply. Von SCHAAFFHAUSEN (1963) successfully grew maize undersown with *Dolichos*. The latter remained standing after the maize harvest and could be used as a green fodder during the dry season. Because of resprouting, it was possible to grow a large biomass of green manure during the short rainy season without replanting or tillage, thereby conserving humus. By selecting appropriate species and varieties - drought-resistance, length of growing period and compatibility with the main crop are the most important selection criteria - the demands of site and rotation can be reconciled to a great extent.

In the **dry savanna**, there is only one reliable cropping season. The cost of land use for green manure is therefore high. For this reason ARAKERI et al. (1962) advise against green manuring in such areas. But wherever possible, i.e. where enough land is available, an intensive fallow should be planted rather than a natural fallow. These areas are typically short of N and C, so the nitrogen effect on the following crop is particularly attractive. Green manure plants also improve the penetration of roots through the clay-rich B horizons, thereby markedly enhancing cropping conditions. However, improving the carbon status of soils in this zone is more difficult, especially on sandy soils (JAISWAL et al. 1971; CHARREAU 1975; GUIRAUD et al. 1980). Agroforestry, rather than green manuring or intensive fallowing, comes into its own in this zone (see Chapter 3).

In the **highlands** water supplies are usually sufficient. However, low temperatures can be a limiting factor. In the cool, humid higher elevations of Rwanda, this constraint affects not so much the formation of biomass yield as its decomposition in the soil (PIETROWICZ and NEUMANN 1987).

4.14 References

AGBOOLA, A.A., and FAYEMI A.A.A. (1972a): Fixation and excretion of nitrogen by tropical legumes. Agronomy Journal 64 (4): 409-412.

AGBOOLA, A.A. and FAYEMI, A.A.A. (1972b): Effect of soil management on corn yield and soil nutrients in the rain forest zone of Western Nigeria. Agronomy Journal 64 (5): 641-644.

AGBOOLA, A.A. (1975): Problems of improving soil fertility by the use of green manuring in the tropical farming system. FAO Soils Bulletin No. 27: 147-164.

AGBOOLA, A.A., OBIGBESAN, G.O. and FAYEMI, A.A.A. (1975): Interrelations between organic and mineral fertilizers in the tropical rainforest of Western Nigeria. FAO Soils Bulletin No. 27: 337-351.

AGBOOLA, A.A. (1981): The effects of different soil tillage and management practices on the physical and chemical properties of soil and maize yield in a rainforest zone of Western Nigeria. Agronomy Journal 73 (2): 247-251.

ALLISON, F.E. (1973): Soil organic matter and its role in crop production. Developments in Soil Science Nr. 3, Elsevier, Amsterdam.

ARAKERI, H.R., G.V. CHALAM, P. SATYARANAYANA, and R.L. DONAHUE (eds.) (1962): Soil Management in India. Bombay, Asia Publishing House, 619 pp.

AYANABA, A . and W. DART (eds) (1977): Biological nitrogen fixation in farming systems of the tropics. Symposium held at the Internat. Inst. of Trop. Agric. Ibadan in October 1975. Chichester. 377 pp.

BAUR, M. (1949): Humusversorgung - Bodenfruchtbarkeit. Münster, Hiltrup.

BEETS, W.C. (1982): Multiple cropping and tropical farming systems. Aldershot, Gower, 156 pp.

BOGUSLAWSKI, E. von (1981): Ackerbau, Grundlagen der Pflanzenproduktion. Frankfurt, DLG-Verlag, 427 pp.

BOUHARMONT, P. (1979): L'utilisation des plantes de couverture et du paillage dans la culture du caféier Arabica au Cameroun. Café, Cacao, Thé 23 (2): 75-102.

BUANEC, B. Le and JACOB, B. (1981): Dix-sept ans de culture motorisée sur un bassin versant du centre Côte d'Ivoire. Agron. Trop. 36 (3): 203-211.

BURNETT, C.A. (1975): The use of organic fertilizers in Brazil. In: FAO (1975): Organic Materials as Fertilizers. FAO Soils Bulletin 27. 305-311. Rome.

CHARREAU, C. (1975): Organic matter and biochemical properties of soils in the dry tropical zone of West Africa. In: FAO (1975): Organic Materials as Fertilizers. FAO Soils Bulletin 27. 313-316. Rome.

CHU, L.C. (1979): The use of Azolla in rice production in China. In: IRRI (1979): 375-394.

DO VAN LONG (1978): Nährstoffkonkurrenz zwischen Kulturpflanzen und Unkräutern bei gesteigerter Düngung. Dissertation, Justus-Liebig-Universität, Gießen.

DRESSLER, J. (1983): Standortgerechter Landbau (SGL) im tropischen Bergland. Situationen und Entwicklungsmöglichkeiten landwirtschaftlicher Kleinbetriebe in Rwanda. Schlußbericht zur Forschung im Auftrag der Deutschen Gesellschaft für Technische Zusammenarbeit (GTZ). Eschborn.

DUNCAN, A. (1975): Economic aspects of the use of organic materials as fertilizers. In: FAO (1975): 353-378.

EGGER, K. (1982): Methoden und Möglichkeiten des Ecofarming in Bergländern Ostafrikas. In: Gießener Beiträge zur Entwicklungsforschung, Reihe I, Bd. 8: 69-96.

EGGER (1983): Bericht über den Besuch des Projektes 69.2040.9 Rwanda im Februar und März 1983. unveröffentlichtes Manuskript. Heidelberg.

FAO (1979a): China: Azolla propagation and small scale biogas technology. Rome, FAO Soils Bull. No. 41, 81 pp.

FAO (1979b): China: Recycling of organic wastes in agriculture. Rome, FAO Soils Bull. No. 40, 106 pp.

FLAIG, W., NAGAR, B.H., SÖCHTIG, H. and TIETJEN C. (1978): Organic materials and soil productivity. Rome, FAO Soils Bull. No. 35, 119 pp.

FLOQUET (1990): Conservation of soil fertility by peasant farmers in Atlantique Province Benin. In Kotschi, J. (ed.) (1990): Ecofarming practices for tropical smallholdings. Weikersheim.

GETAHUN, A. (1981): Increasing food production in the agroforestry systems of the humid and tropical lowlands. I.I.T.A. Research Briefs 2 (3): 2-7.

GLIEMEROTH, G. (1958): Untersuchungen über den Einfluß von organischer Düngung, Pflanzenbestand und Bearbeitung auf Humusgehalt und Aggregateigenschaften eines Lößlehms. Z.f. Acker- und Pfl.-bau, 105: 353-376.

GRAHAM, P.H. (1981): Some problems of nodulation and symbionic nitrogen fixation in *Phaseolus vulgaris L.*: A Review. Field Crops Research 4: 93-112.

GUIRAUD, G., GANRY, F. and LLIMOUS, GISELE (1980): Action de différents résidues de recolte en sol sableux tropical. Estimation au moyen de N 15. Agron. Trop. 35 (3): 220-224.

GUTBROD, K.G. (1982): 'Azolla' - Landwirtschaftliche Nutzungsformen. Abriß der Ansprüche von 'Azolla' an die Kultivierung. Unveröffentlichter Projektentwurf, GTZ/Universität Göttingen, 4 pp.

HAMDI, Y.A. (1982): Application of nitrogen-fixing systems in soil management. Rome, FAO Soils Bull. No. 49, 188 pp.

HOWARD, A. (1943): Mein landwirtschaftliches Testament. (Übersetzung des englischen Originals von 1943 bei Edition Siebenreicher) Volkswirtschaftlicher Verlag, 254 pp. 1979. München.

IITA (1977): Annual Report 1976. International Institute of Tropical Agriculture. 97-98. Ibadan/Nigeria.

IITA (1981): Annual Report for 1980. International Institute of Tropical Agriculture. 1-100. Ibadan/Nigeria.

IRRI (1979): Nitrogen and Rice. International Rice Institute. Los Banos/Philippines. 499 pp.

JAISWAL, P.L., WADHWANI, A.M., JAIN, M.K. and CHHABRA, N., (Eds.) (1971): Handbook of manures and fertilizers. 2nd edition. Indian Council of Agricultural Research, New Delhi. 396 p.

KAHNT, G. (1983): Gründüngung. 2. verb. Auflage. DLG-Verlag, Frankfurt/M. 146 pp.

KANG, B.T and OKIGBO, B.N. (1981): Land use and cropping systems in the humid and subhumid tropics of West Africa. Paper presented at a Conference in Montpellier/France, 24 pp.
KARUNAIRANJAN, R.D. (1980): Gründüngung in den Tropen. IFOAM, 35: 18-21.

KEMPER, B. and DERPSCH, R. (1981) Results of studies made in 1978 and 1979 to control erosion by cover crops and no-tillage techniques in Parana, Brazil. Soil and Tillage Res. 1. 253-267.

KING, F.H. (1911): Farmers of Forty Centuries. Democrat Printing Co., Madison Wisc. 441 pp.

KLAPP, E. (1967): Lehrbuch des Acker- und Pflanzenbaus. 6. Aufl. Berlin, Parey, 603 pp.

KÖHNLEIN, J. (1964): Über die Beziehung zwischen Ertragsbildung, Bodenfruchtbarkeit und Humus und die Beeinflußbarkeit des Faktors "Humus" auf landwirtschaftlich genutzten Böden. Schriftenreihe der landw. Fak. der Univ. Kiel, Heft 37: 5-40

KOTSCHI, J., PFEIFFER, J. and GROSSER, E. (1982): Fachseminar Standortgerechter Landbau. DSE. Feldafing.

KOTSCHI, J. (ed.)(1990): Ecofarming practices for tropical smallholdings. Margraf Verlag. Weikersheim.

KULLMANN, A. (1966): Zur Dynamik der Bodenaggregate und deren Beeinflussung durch organische Substanzen. In: Sitzungsberichte, Berlin (Ost) 15 (10).

LAUER (1956): Vegetation, Landnutzung und Agrarpotential in El Salvador. Schriften des geographischen Instituts der Universität Kiel. Bad. 16:(1).

LINDERMAN, R.G. (1970): Plant residue decomposition products and their effects on host roots and fungi pathogenic to roots. Phytopathology 60 (1): 19-22.

LITZENBERGER, S.C. and HO, T.L. (1961): Utilizing *Eupatorium odoratum L.* to improve crop yield in Cambodia. Agronomy J. 53: 321-324.

LOHNIS, F. (1926): Nitrogen availability of green manures. Soil Sci. 22: 253-290.

LUDWIG, H.D. (1967): Ukara - Ein Sonderfall tropischer Bodennutzung im Raum des Viktoria-Sees. München, Institut für Wirtschaftsforschung Afrika-Studien Nr. 22, Weltforumverlag, 251 pp.

LUGO-LOPEZ, M.A., R. PEREZ-ESCOLAR and T.W. SCOTT (1978): Influence of fertilizer N and legume crop residues on maize yields. Proc. Carib. Food Crops Soc./Surinam Symp. on maize and peanut, 1978, 15: 39-45.

MILLER, D.E. and KEMPER, W.D. (1962): Water stability of aggregates of two soils as influenced by incorporation of alfalfa. Agronomy. J. 54: 494-496.

MINISTRY OF AGRICULTURE, NEW DELHI (1975): The use of organic fertilizers in India. In: FAO Soils Bull. No. 27: 273-314. Rome.

NEUMANN, I. and PIETROVICZ, P. (1983): Jahresbericht der Forschungsabteilung im Projekt Agro-Pastoral de Nyabisindu/Rwanda, 1982. Unveröffentlichter Forschungsbericht, GTZ/Eschborn.

NUTMAN, S.P. (ed.)(1976): Nitrogen Fixation in Plants. Cambridge University Press. Cambridge.

NWOBOSCHI, LOUIS C. (1981): Soil productivity aspects of agri-silviculture in the West African rain forest zone. Agro-Ecosystems 7: 263-270.

NYE, P.H. and GREENLAND, D.J. (1960): The soil under shifting cultivation. Farnham Royal, Commonwealth Bureau of Soils, Techn. Communication No. 51: 156 p.

NYOKA, G.C. (1982): The influence of fallow period on weed, vegetation and rice yield in Sierra Leone. Tropical Pest Management 28 (1): 1-9.

OFORI, C.S. (1980): The use of organic materials in increasing crop production in Africa. In: FAO (1980): Organic Recycling in Africa. FAO Rome. FAO Soils Bulletin No. 43, 121-128.

OKIGBO, B.N. (1977): Role of legumes in small holdings of the humid tropics of Africa. in: Proc. of a workshop, 2 Aug. 1976, College of Trop. Agric. Hawaii, Miscellaneous Publ. 145: 97-117.

OKIGBO B.N. (1980): A review of cropping systems in relation to residue management in the humid tropics of Africa. In: FAO (1980): Organic Recycling in Africa. FAO Rome. FAO Soils Bulletin No. 43, 13-37.

PIETROWICZ, P. and I.F. NEUMANN (1987): Fertilization et amélioration des sols. Étude sur l'application d'engrais vert, de la fumure organique et des engrais mineraux. Études et Éxperiences No. 11. Projet Agro-Pastoral/GTZ. Eschborn.

RAMAKRISHNAN, P.S. and TOKY, O.P. (1981): Soil nutrient status of hill agro-ecosystems and recovery pattern after slash and burn agriculture (Jhum) in North-Eastern India. Plant and Soil 60 (1): 41-64.

RAQUET, K. (1990): Green manuring with fast growing shrub fallow in the tropical highland of Rwanda. In: Kotschi, J.(ed.)(1990): Ecofarming practices for tropical smallholdings. Weikersheim.

REHM, S. and ESPIG, G. (1976): Die Kulturpflanzen der Tropen und Subtropen: Anbau, wirtschaftliche Bedeutung, Verwertung. Ulmer. Stuttgart. 504 S.

REINMUTH, E. (1968): Beeinflussung des antiphytopathogenen Potentials des Bodens durch organische Düngung und Vorfrucht. Wien, Pflanzenschutzberichte, Bd. 38: 23-231.

RODRIGUEZ, M.J. (1972): Algunos aspectos del cultivo del mais (Zea mays), Revista ICA/Kolumbien 7 (2): 89-110.

ROOSE, E. (1981): Dynamique actuelle de sols ferrallitiques et ferrugineux tropicaux d'Afrique Occidental. Traceaux et Documents de L'ORSTOM, No. 130, Paris, ORSTOM, 569 pp.

SANCHEZ, P.A., D.A. BANDY, J.H. VILLACHICA and J.J. NICHOLAIDES (1982): Amazon basin soils: management for continuous crop production. Science 216: 821-827.

SANCHEZ, P.A. and J.G. SALINAS (1981): Low-input technology for managing oxisols and ultisols in tropical America. Adv. in Agron. 34: 279-406.

SAUERLANDT, W. (1948): Grundlagen der Bodenfruchtbarkeit Humusdüngung und Bodengare. Lüneburg, Kinau, 127 S.

SCHAAFHAUSEN, R. von (1963): *Dolichos lablab* or Hyacinth Bean: Its uses for feed, food and soil improvement. Econ. Bot. 17: 146-153.

SCHULTZ-LUPITZ (1895): Zwischenfruchtbau auf leichten Böden. Arb. der DLG, Berlin.

SCHWEIZERISCHE STIFTUNG ZUR FÖRDERUNG DES BIOLOGISCHEN LANDBAUS (Hrsg.) (1981): Projekt für alternativen Landbau in Cochabamba, Bolivia (PAC). Oberwil 20 pp.

SINGH, P.K. (1975): Use of organic materials and green manures as fertilizers in developing countries. In: FAO Soils Bull. No. 27: 19-30.

SINGH, P.K. (1979): Use of *Azolla* in rice production in India. Symposium on Nitrogen and Rice, Sept. 1978, IRRI, Los Banos, Philippines. In: IRRI (1979), 407-418.

TALINEAU, J.C., G. HAINNAUX, G. BONZON, C. FILLONNEAU, D. PICARD and M. SICOT (1976): Quelques conséquences agronomiques de l'introduction d'une sole fourragère dans une succession culturale du milieu tropical humide de Cote d'Ivoire. Cah. ORSTOM, Serie Biologie 11 (4): 227-290.

WALTER, H. (1964): Die Vegetation der Erde in Öko-physiologischer Betrachtung. Bd. I., Jena, Gustav Fischer, 592 pp.

WEBSTER and WILSON (1980): Agriculture in the Tropics. Second edition. Longman. London. 640 pp.

WEERARATNA, C.S. (1979): Pattern of nitrogen release during decomposition of some green manures in a tropical alluvial soil. Plant and Soil 53: 287-294.

WENDT, F.W. and N. STARK (1968): The biological and mechanical role of soil fungi. Proc. N.A.S. 60: 497-504.

WHITNEY, A.S. (1982): The role of legumes in mixed pastures. In: GRAHAM and HARRIS (1982): 361-367.

WILLEY, R.W. and OSIRU, D.S.O. (1972): Studies on mixtures of maize and beans *(Phaseolous vulgaris)* with particular reference to plant population. J. Agric. Sci. 79: 517-529

YAACOB, O. and G.J. BLAIR (1981): Effect of legume cropping and organic matter accumulation on the infiltration rate and structural stability of a granite soil under a simulated tropical environment. Plant and Soil 60 (1): 11-20.

YEOH, Chong Hoe (1979): Propagation of Legume Cover Crops in Rubber Plantations. Planter's Bulletin, 159: 54-64.

YOUNG, A. (1976): Tropical Soils and Soil Survey. Cambridge, Cambridge University Press, 467 pp.