2. *PROCESSES*

N-depletion

The rapid decline in soil fertility after clearing a new plot of a forest vegetation is at least partly due to the fact that more soil organic matter is decomposed than is freshly added. Rapid decomposition releases nitrogen and other nutrients for crop growth, but the capital in the soil is depleted rapidly if more than the interest is consumed. Only part of the N mineralised is taken up by the crops. Other fractions are lost by leaching or as gaseous losses. On the project site annual rainfall is 2.0 - 2.5 m, while annual evapotranspiration can be estimated to be about 1.2 m. The surplus of water either runs off the surface of the soil, with a risk of causing erosion, or infiltrates into the soil, carrying mineral nutrients from the soil solution. The rate at which nutrients are transported downwards in the soil depends on the downward movement of water, on the adsorption of the nutrient to the soil and on the degree of bypass flow. If most of the water infiltrates through cracks or macropores bypassing most of the topsoil, leaching will be less severe (Van Noordwijk *et al.*, 1991b). On our project site we found that decaying tree roots from the forest vegetation led to bypass flow. The adsorption of nutrients depends on the adsorption capacity of the soil, in which soil organic matter plays a major role in these soils, and on the nutrient concerned. Nitrogen is of particular interest as the nitrate form is adsorbed much more weakly than the ammonium form. Under acid conditions the microbial transformation of ammonium to nitrate ('nitrification') occurs relatively slowly and this fact helps to conserve nitrogen in the topsoil. Figure 2 gives the results of a simplified model description of leaching on our project site. From the excess rainfall on the left vertical axis we can predict how deeply nitrogen would penetrate if it stays in the ammonium form, as read from the right vertical axis (Van Noordwijk, 1989). The annual leaching depth is about 0.7 m, if 10% of the rainwater disappears as surface run off. For crops with a rooting depth around 0.7 m little leaching would be expected, as long as nitrification is slow. For several crops, however, and especially for maize, the acid conditions in the subsoil below 0.15 m prevent root development. The classical 'high input' solution to soil acidity is the application of large amounts of lime. Liming will accelerate nitrification and may thus increase nitrogen losses by leaching. Choice of acid-tolerant crops

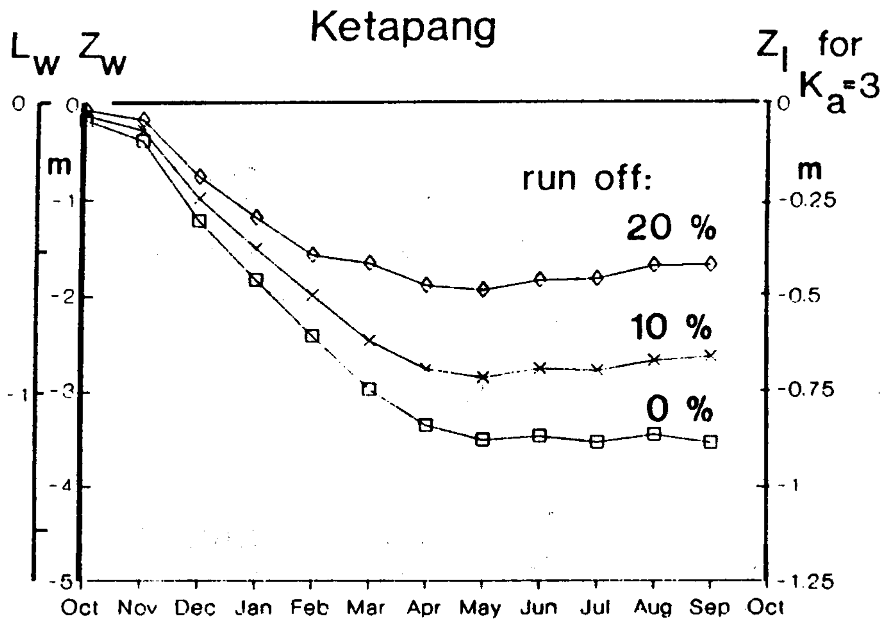

Figure 2. Rainfall surplus in Ketapang and predicted effects on leaching (see text).

and cultivars may be a better solution, with the possible need to add small amounts of lime in the longer run to maintain Ca and Mg levels in the soil. Even with a very shallow root development leaching of N might be prevented if the daily supply of nitrogen, from mineralization or otherwise, would be equa to the daily demand. Supply and demand are usually not completely synchronous however, and especially in the beginning of the growing season surpluses of mineral N in the topsoil will exist. Through leaching such surpluses can be beyond the reach of shallow-rooted crops by the time the crop needs exceed th supply in the topsoil. Figure 3 illustrates this process. Under these conditions intercropping shallow- and deep-rooted crops can be advantageous, e.g. maize and cassava, but the deeprooted component has to develop rapidly. A permanent deep root system, as can be found in certain hedgerow trees in the alley-cropping system, may provide a more secure 'safety-net' (Figure 4) for leaching nutrients. Much speculation exists on the role of trees as 'nutrient pumps', adding nutrients to the topsoil by leaf fall or decaying roots (Young 1989b). In soils as found on the project site, this role cannot ve very important as there is not much to be pumped from the subsoil anyway, in the absence of 'weatherable' minerals. The role of tree roots as a 'safety-net'

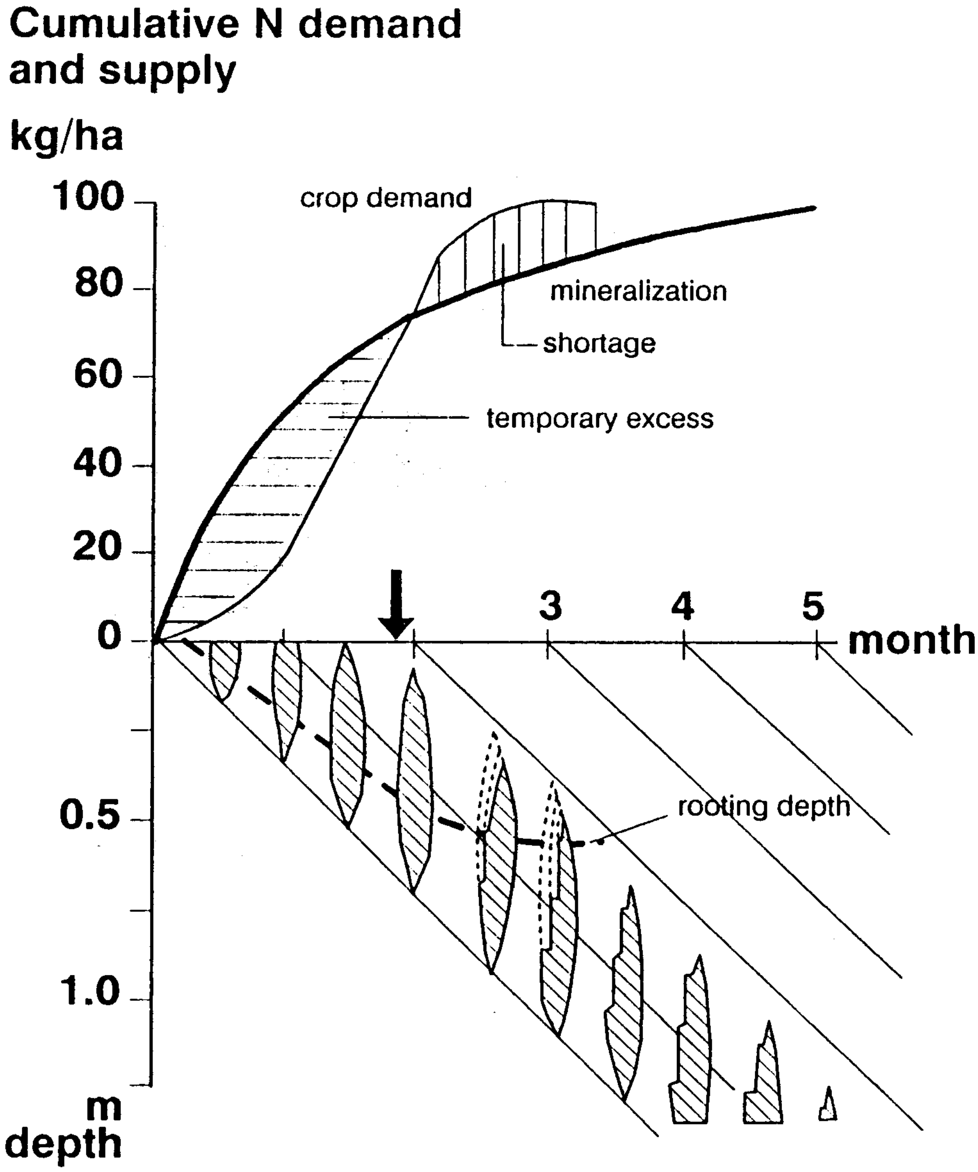

Figure 3. Schematic view of the problem of incomplete synchrony of N-supply by mineralization and N-demand by the crops and its consequences for leaching of N and subsequent recovery by deep-rooted crops.

means that certain inputs will be required to maintain the cropping system, but at least losses will be reduced and the efficiency of using the resources will be increased.

A further possibility to increase nitrogen use efficiency can be found in the stimulation of bypass flow. An effective way of achieving this may be to grow crops on small ridges or mounds, with the soil organic matter or fertilizer source of nutrients above the surrounding soil surface. During heavy rainfall most of the water will infiltrate into the furrows or around

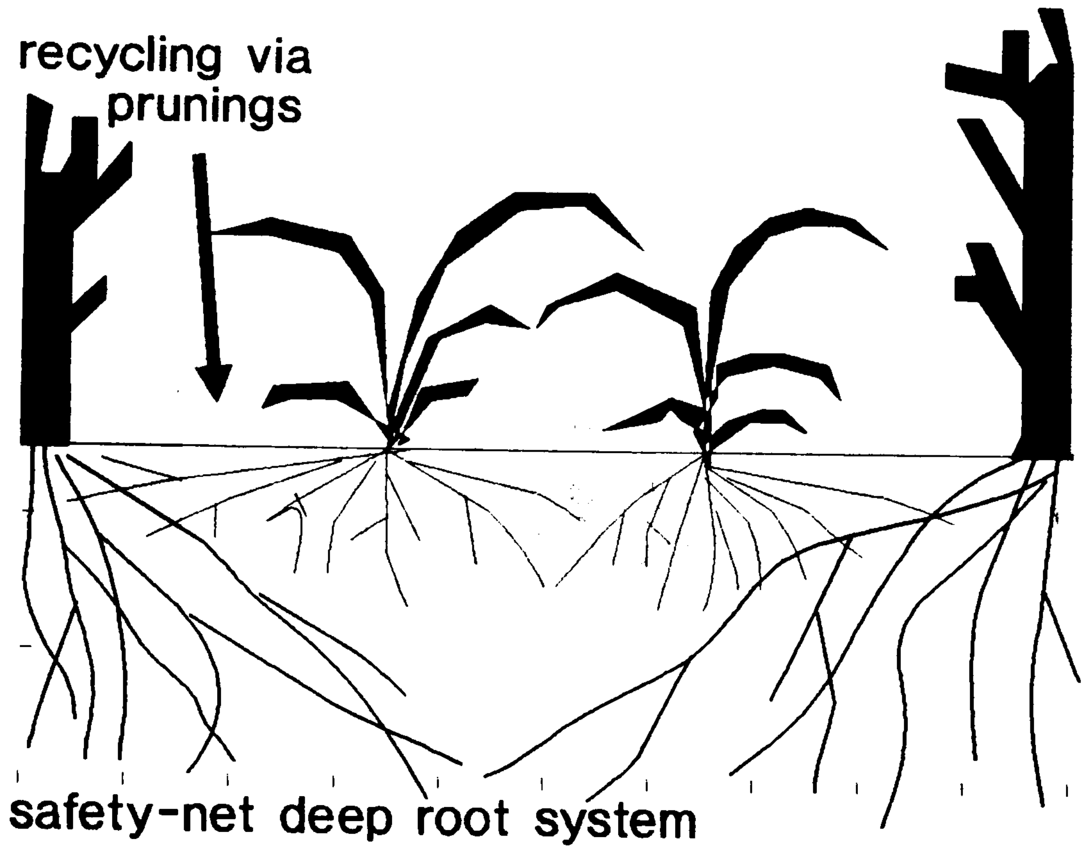

Figure 4. Safety-net role of roots of hedgerow trees when shallow-rooted crops are used.

the mounds and leaching of nutrients will be reduced. This bypass flow may be one of the reasons for the preference for growing crops on mounds as found all over the humid tropics in traditional agriculture.

From this analysis of the problems of conserving nitrogen in the soil, we can formulate ten 'principles' (Table 1) which can be used to improve nitrogen use efficiency and hence improve the sustainability of the system.

N-management principles for acid soils in the humid tropics

1. protect topsoil, maintain infiltration rate,
2. control weed growth, esp. Imperata,
3. maintain acceptable yield per unit labour input,

INCREASE N-use efficiency by reducing N-losses:

4. maintain soil organic matter content: use all crop residues, include cover crops or tree mulch,
5. improve synchronization of N-mineralization and demand by the crop,
6. improve synlocalization of N-supply and crop roots, stimulate bypass flow of water,
7. increase rooting depth of crops c.q. crop combinations, create " safetynets" of deep roots,
8. maintain favourable properties of acid soils: slow nitrification, little gaseous N-losses & leaching,

INCREASE N-inputs at improved efficiency:

9. include N2-fixing crops in cropping pattern,
10. use low rates of N-fertilizer, at right time and place.

Table 1. N-management principles.

Maintaining soil organic matter and preventing erosion

After opening a new site the soil organic matter which was 'inherited' from the previous vegetation steadily disappears. A continuous input is required to stabilize the soil organic matter content. Soil organic matter increases the adsorption capacity for nutrients and is important for maintaining soil structure and hence to reduce erosion. If a soil organic matter content of 2% is to be maintained in the humid tropics, an annual input of 8.5 t/ha of aboveground dry weight is required according to calculations by Young (1989a). As this target amount cannot usually be reached by maintaning all crop residues in the field, additional inputs through manure, cover crops or hedgerow trees are required to make the cropping system sustainable. Of course this target value is a first approximation only, and further research on the dynamics of soil organic matter is required to obtain more reliable estimates. Not all sources of organic matter have an equal value in this respect. Rapidly decomposing, usually N-rich material may be a very valuable as source of nutrition to the next crop, but it contributes little to the soil organic matter content. A slowly decomposing mulch on top of the soil may be the best protection against erosion. For the various functions of organic inputs, diversity in the sources of organic matter may be required.

Weed infestation

The most serious weed in this area is *Imperata* (alang-alang). As soon as open spaces occur in the cropped field, seeds may germinate. Once established, the plants spread rapidly through their rhizomes and they are difficult to eradicate. 'Weeding' the soil may lead to an effective dispersal of parts of the rhizome still capable of regrowth. Frequent weeding or cutting is needed to kill the plants. The plants are not very tolerant of shade, however, and a permanent cover may both prevent infestation and reduce the vigour of established plants. Reforestation of alang-alang fields is complicated by the 'allelopathic' effects of the plant on germination and early growth of other plants, including trees. Around the project site only one tree, *Peltophorum pterocarpa*, is seen as a spontaneous colonizer of alang-alang fields. When alang-alang infestation of a cropped field has not gone too far, a short period of growing vigorous climbing leguminous cover crops, such as *Mucuna utilis*, may still control the spread of the weed (Hairiah et al., 1991). By climbing the *Imperata* leaves and pulling them to the ground the necessary

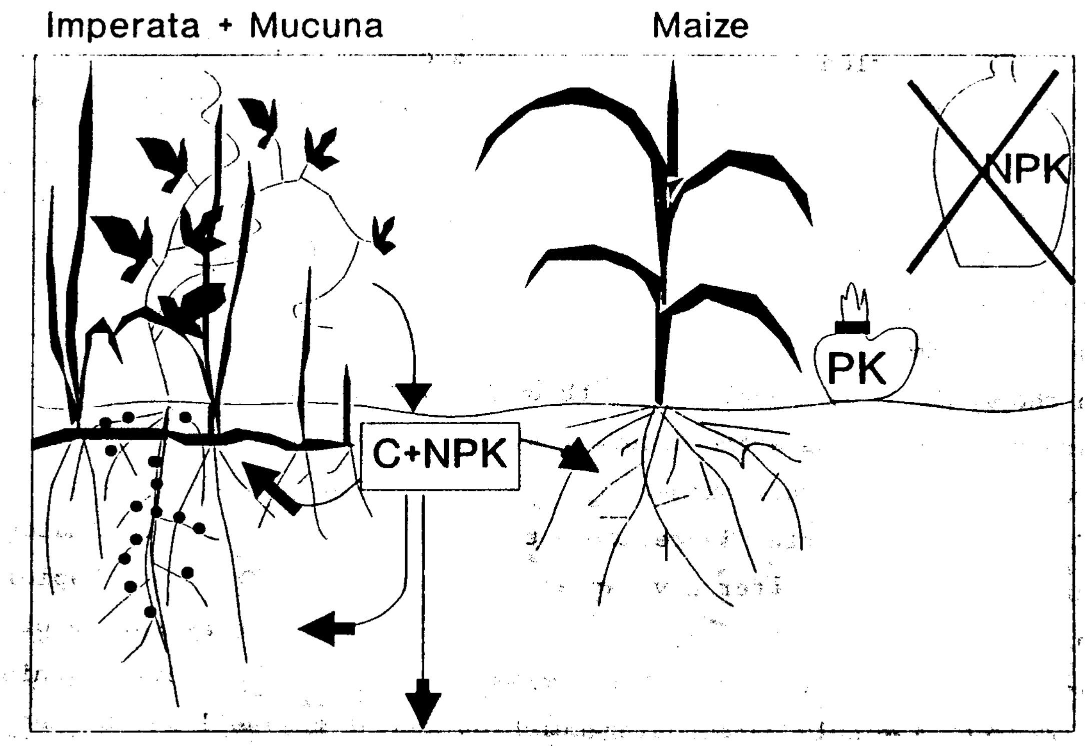

Figure 5. Schematic view of the possible use of *Mucuna* to reclaim *Imperata* land for maize cropping.

shading of the grass leaves is achieved. For more serious infestations cover crops with a longer life cycle are needed. Attempts at reclamation of alang-alang fields by such purely biological means have only been partially successful in Indonesia.
In combination with herbicides to give the first blow to the weed, however, cover crops can be useful.

3. *COMPONENTS* and *CROPPING SYSTEMS*

Figure 6 shows the cropping calendar for the three types of cropping systems tested.

Cassava-based system
In a number of experiments cassava is grown with either maize, rice or soybean as an intercrop during the first 3 to 4 months. Cassava is harvested after 9 months and for the remaining 3 months either a leguminous cover crop (*Mucuna*) is grown or a short-cycle, acid-tolerant cowpea.

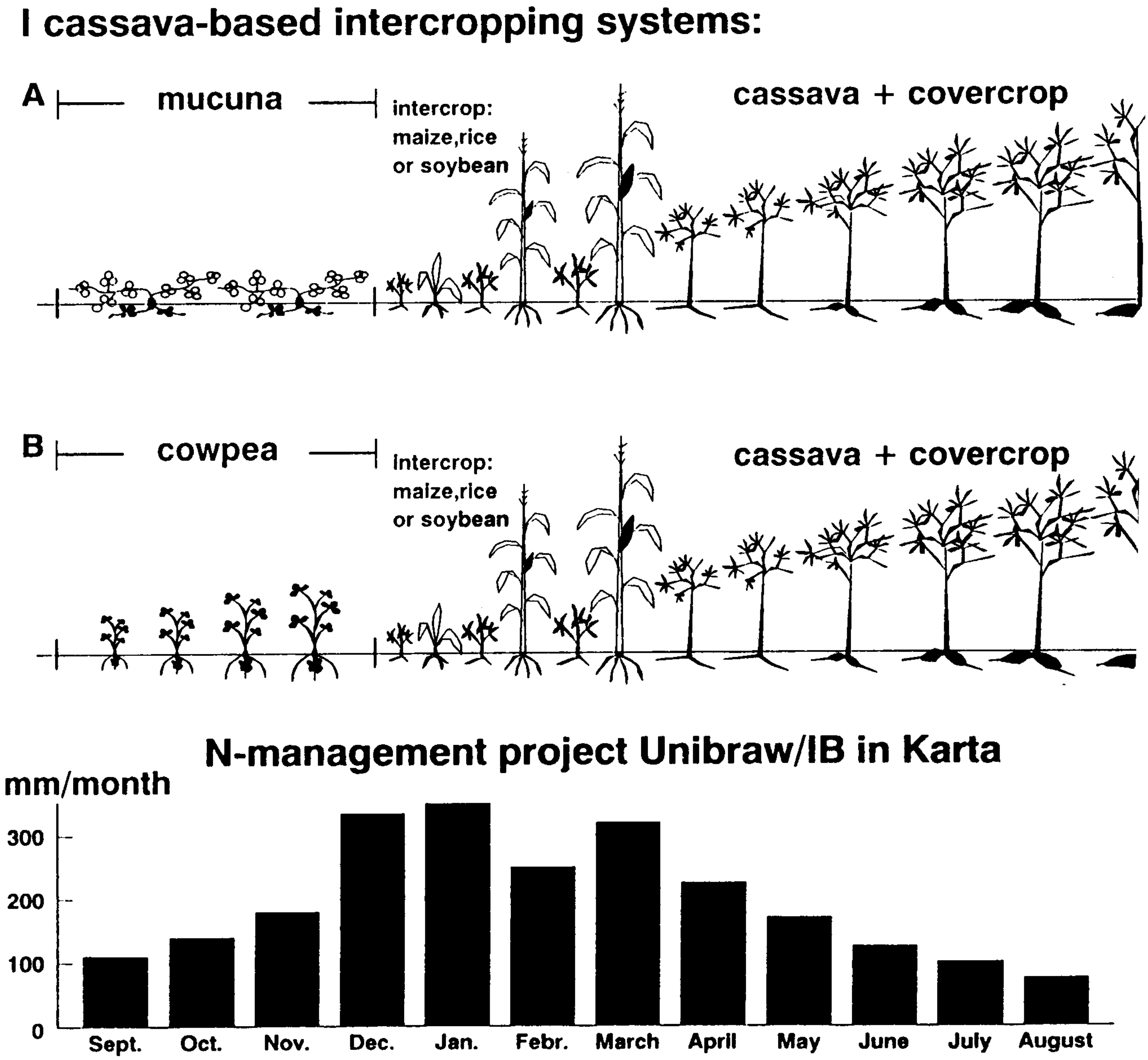

Figure 6. Crop calendar cassava-based cropping systems used in Ketapang.

In years with a more-than-average dry period, these crops can fail. Initially a local variety of cassava was used, but this proved to be too vigorous under the existing conditions, producing tall stems and few tubers, which were relatively difficult to harvest. Therefore a switch to another cassava variety, selected in Indonesia, was made: it forms a lower canopy and more tubers which are easy to harvest. It is considered to be less tasty, however, and might be more shallowly rooted. In the intercropping system used the first-season crops should be harvested within 4 months to allow a proper development of the cassava. Initially, upland rice varieties with too long a cycle were used. Figure 7 shows the rooting pattern of the crops used on this soil. Maize is

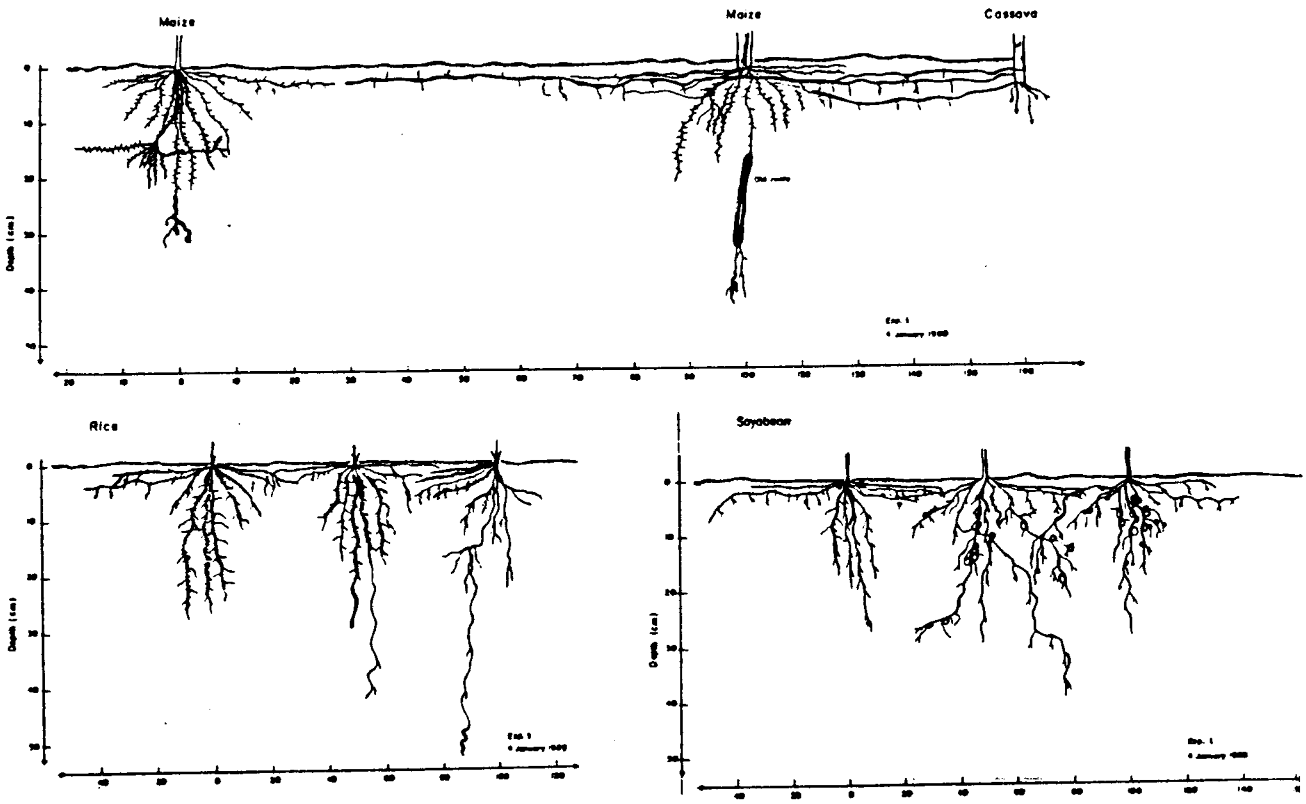

Figure 7. Root pattern of maize, cassava, upland rice and soybean four weeks after planting.

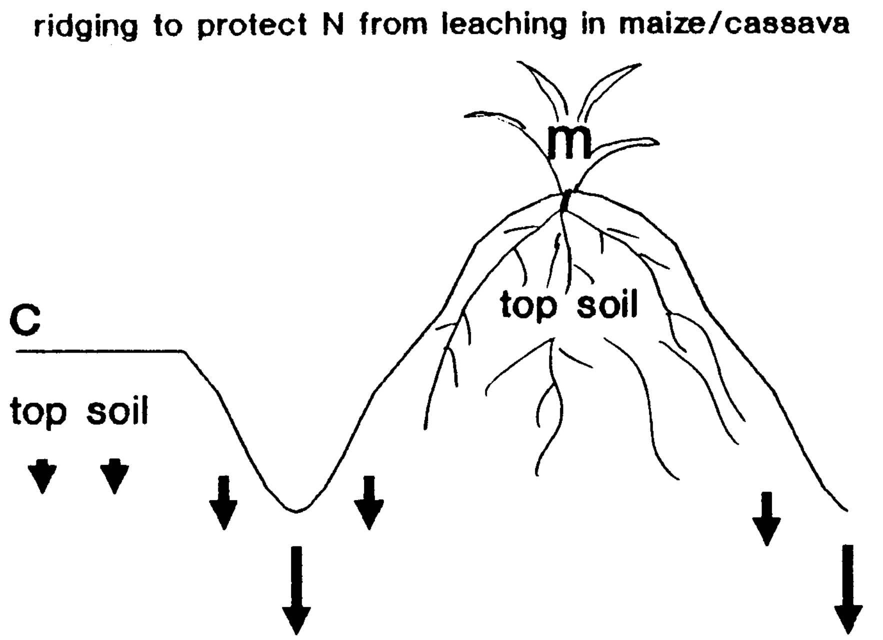

Figure 8. Schematic effect of maize ridge on heterogeneity of infiltration of rain and hence on the possibility of increasing N-use efficiency by improved synlocalization of N and roots.

very shallow-rooted, upland rice is relatively deep-rooted and soybean is intermediate. The cassava variety used has mainly superficial roots, which ma; extend to 5 m from the cassava stem. The crop thus is an effective 'scavenger'; for performing field experiments this large spread leads to problems, a: large border areas are necessary.

In the first experiment, which is in its fifth planting season now upland rice shows the clearest positive response to the extra input of nitrogen and organic matter in the *Mucuna* residue as compared to the cowpea intercrop', but also in the cassava monoculture a response could be seen. Maize performed poorly in the fifth year of cropping, even at the highest N-fertilizer level tested, despite annual applications of P, K and Zn.

In another experiment the *synlocalization* option for N-management (De Willigen and Van Noordwijk, 1989) is tested in the form of growing maize on ridges in the hope that nitrogen supplied in the ridge can be protected from leaching (Fig. 8). Crop performance suggests a spectacular increase in the recovery of N applied as fertilizer in this system.

Maize/legume rotation

The second type of cropping system investigated in the project (Fig. 9) is a rotational system of maize, soybean and leguminous cover crops, with a grass fallow as control. Results of experiments with this cropping system have so far shown that a leguminous cover crop can contribute an amount of nitrogen to a subsequent maize crop similar to an amount of fertilizer N (urea, given in two splits) of about 60 kg per ha. Crop performance suggests that differences

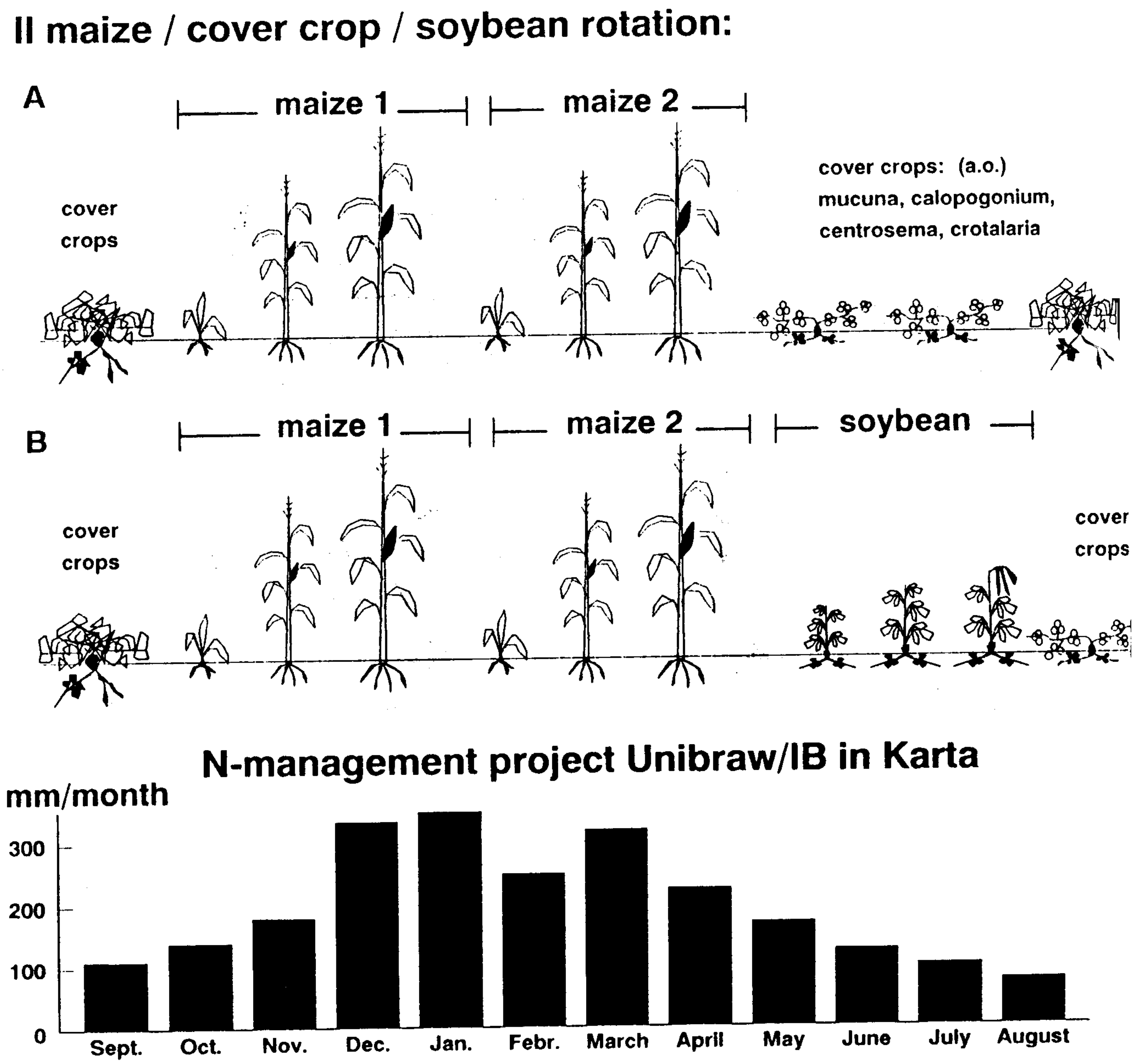

Figure 9. Cropping calendar for rotational systems of maize, soybean and leguminous cover crops.

Table 2. Suitability of leguminous cover crops (modified from Hairiah and Van Noordwijk, 1989).

	Form	Duration (months)	Biomass at 3	6 MAP	*Imperata* contr. 4	8 MAP	Root system	Nodulation
Mucuna pruriens utilis	c	5	+++	++	++	+[1]	shallow	++
Mucuna deeringiana	c	9	+++	+++	++	++	shallow	++
Calopogonium mucunoides	c	perenn.	++	+++	++	0	medium	+
Crotalaria juncea	e	8	++	++	+	++	deep	+
Centrosema pubescens	c	perenn.	+	++	0	0	deep	+
Pueraria phaseleoides	c	perenn.	+	++	+	++	deep	++

1. *Imperata* regenerating.

in the rate of decomposition of the various residues are of practical importance. *Mucuna* residue decomposes rapidly. It gives the best effect on the first crop of maize, but it is inferior to *Calopogonium* residue in its effect on the second crop of maize. A striking phenomenon in this experiment is that *Crotalaria juncea*, a cover crop with good nodulation and high biomass production, has a strongly negative effect on a subsequent maize crop, especially during germination and early growth stages.

Leguminous cover crops do not only provide organic matter and N to the cropping system, but can also play a role in controlling weeds, especially *Imperata cylindrica* (Fig. 7). In a side plot, next to a "bush fallow" plot, a 3-year old stand of *Pueraria phaseoloides* was found to give almost complete control of *Imperata*. Experiments with cover crops to reclaim *Imperata*-infested land have shown that cover crops such as *Mucuna utilis* can be effective in combination with herbicides, but that without herbicides a period of 3 months is too short to have a substantial effect on *Imperata*. Experiences with various cover crops are summarized in Table 2.

In a further experiment the growth of *Imperata* is compared with that of *Mucuna* and maize, as influenced by aggravated acid soil conditions as would occur if most of the topsoil were lost by erosion. Although even the weeds would show a retarded growth under such circumstances, their relative tolerance is much higher than that of the cover crops used, let alone maize. The use of moderate amounts of phosphate fertilizer and lime would not be sufficient to return to acceptable conditions for crop production.

Hedgerow intercropping

The third type of cropping system tested is "alley cropping" or "hedgerow intercropping" (Fig. 10). In one experiment maize intercropped with six types of hedgerows (five tree species and one mixed hedgerow system) is compared with a monoculture control. No N-fertilizer is used in this experiment and no soil tillage is used. For some tree species a second pruning during the maize growth is obviously necessary, for other species such as the local tree species, *Peltophorum pterocarpa*, pruning once is enough. This tree seems to be promising for hedgerow intercropping systems because of its relatively deep root system (van Noordwijk *et al.*, 1991a). It is not nodulated, however, and alternation of rows of *Peltophorum* and the well-nodulated *Gliricidia* may be profitable as *Gliricidia* nodulated close to the *Peltophorum* hedegerows as well (Van Noordwijk and Dommergues, 1990). The growth of maize in between the hedgerows of *Peltophorum* was satisfactory during the fourth cropping season of this experiment where no fertilizer nitrogen is used, but small amounts of P and Zn have been added to the soil. Figure 11 shows the aboveground geometry of this system with various trees. In fact, for each tree a different regime of pruning and spacing of the hedgerows should be used to get optimum results. As aboveground management of the tree may have belowground consequences the present experiment is only a first step.

In a further experiment with seven trees the effect of pruning height on biomass production and root distribution is investigated. The height of stem at which the trees are pruned affects the number of roots originating at the stem base and hence root distribution, as demonstrated with *Peltophorum*

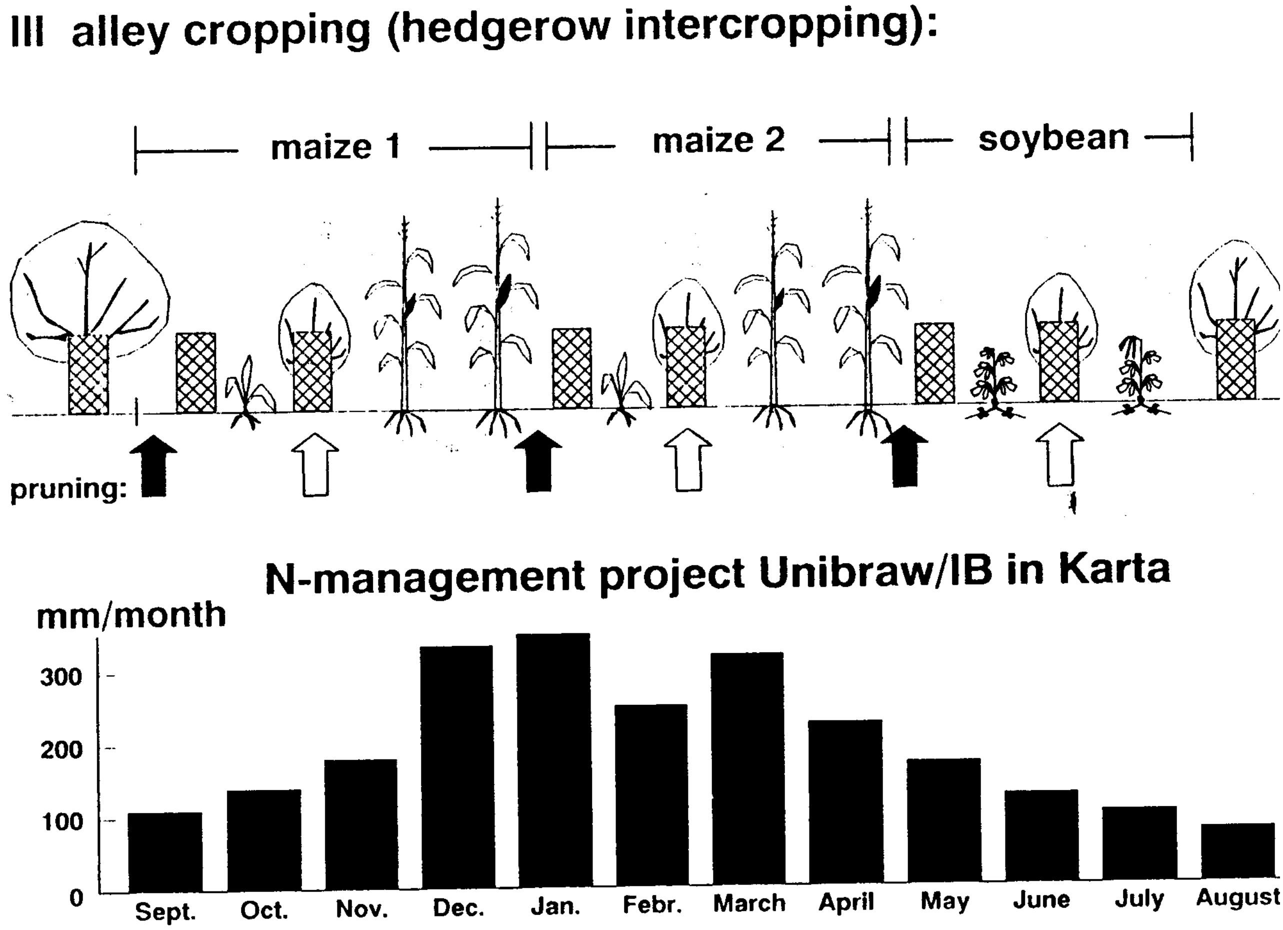

Figure 10. Crop calendar for the hedgerow intercropping system.

pterocarpa. When the trees are left unpruned for six months prior to pruning, a considerable amount of firewood (stems of more than 2 cm diameter) can be produced as well as mulch (leaves and fine stems). It became clear that two tree species, *Albizia falcataria* and *Erythrina orientalis*, even at the high tree density of this experiment have a canopy which is so open that *Imperata* can infest the plots; the other trees provide sufficient shade to prevent this. This observation shows that rows of trees may provide a low-cost weed control system, if planted sufficiently close together. Experiences with various species of hedgerow trees are summarized in Table 3.

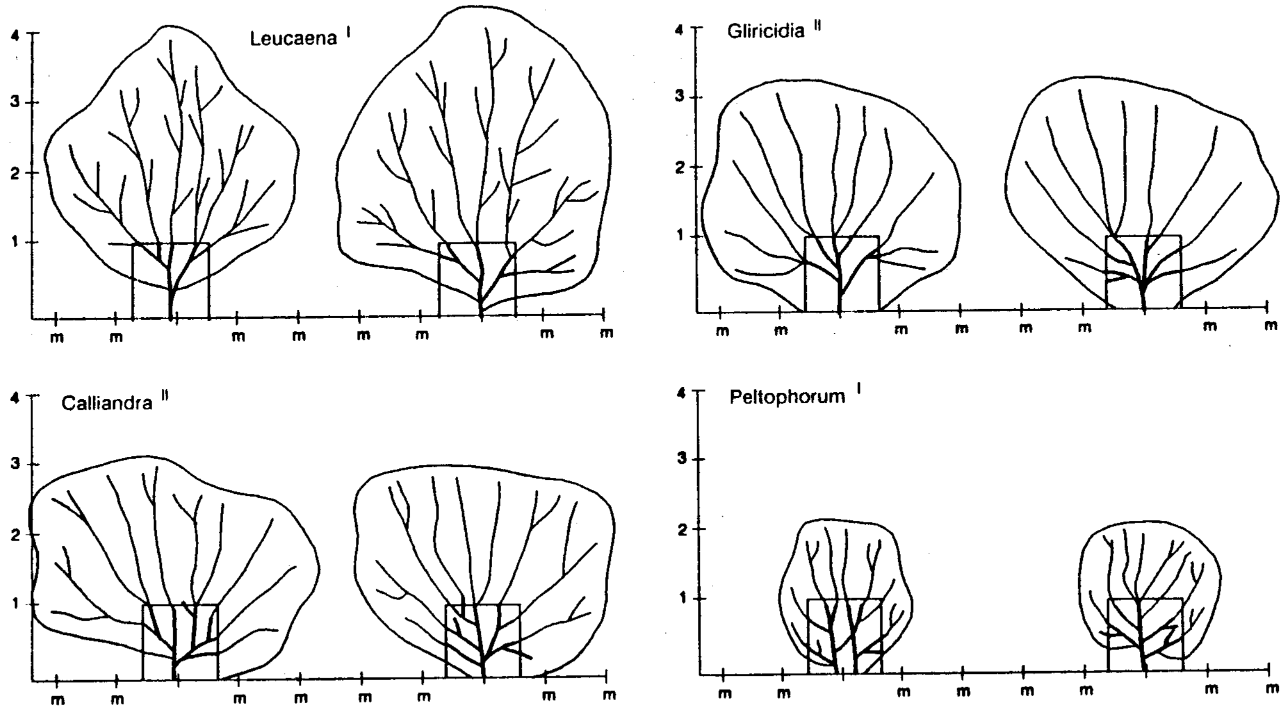

Figure 11. Transsect of the tree canopy at harvest time of the maize, three months after the last pruning.

An experiment which seems to be interesting now would involve planting of rows of *Peltophorum* in alang-alang fields, sow a *Mucuna* cover crop at the end of the second year and three months later prune the trees to obtain the first food crop. Based on our experiences so far, such a procedure might be a labour-effective, low-cost reclamation technique.

Table 3. Suitability of hedgerow trees, based on experience in Ketapang.

	Rooting depth[a]	Horizontal roots[b]	Nodulation	Decomposition	2nd pruning required[c]	Weed control after nine month growth[d]	Firewood quality	Firewood quantity
Leucaena leucocephala	0	--	0	fast	yes	0	+	+
Gliricidia sepium	0	---	++	very fast	yes	0	+	0**
Erythrina orientalis	++	-	+	fast	no	-	+	0
Calliandra calothyrsus	0	---	++	medium	yes	+	-	++
Peltophorum pterocarpa	+*	-	0	slow	no	+	+	+
Albizia falcataria	0	---	+	medium	yes	-	+	++
Cassia siamea	++	--	0	fast	yes	+	+	++

a. 0 = confined to topsoil (0 - 20 cm), + = some roots in subsoil (20 - 60 cm), ++ = relatively deep-rooted (> 60 cm). * When unpruned *Peltophorum* is deep-rooted.

b. - = few roots only in topsoil inbetween crop roots, -- = many, --- = very many.

c. After pruning hedgerows at planting time of the maize certain trees have to be pruned a second time to avoid excessive shading of maize.

d. Nine months after the last pruning cycle *Imperata* control was assessed for trees with a 2.5 m spacing between hedgerows.

e. Tree products when unpruned for 9 months. ** *Gliricida* produces sticks which can be used e.g. for fencing

4. COMMUNICATION BETWEEN RESEARCHERS AND FARMERS

The experiments were started primarily by and for researchers to obtain a better understanding of the processes governing soil-plant relations under given soil and climatic conditions and to test a number of hypotheses and options for sustainable cropping systems. In setting up the experiments, however, actual farming conditions in the area were closely approached. The nightwatches and labourers employed by the project provided the main feedback from the local farming community in the initial years. In 1990 an 'open day' was arranged to discuss the results obtained so far with farmers, extension workers and researchers.

The following points were raised, mainly by farmers, during the discussion on that day:

* Cassava varieties used by the farmers now suffer from yellowing of the leaves, the ones they see here do not. As explained by a cassava expert in the public this yellowing is probably due to bacterial blight. The cassava variety Aldira I used in the N-project is less susceptible than the local variety.
* Cassava plant spacing. In the project, cassava plant density is higher than the officially recommended one for cassava in intercropping with rice and maize. In the project a "cassava-based" cropping system is investigated with emphasis on cassava. For a wider plant spacing of cassava one may expect a more open canopy at the harvest of the intercrop and hence more chance of infestation by *Imperata*. Because of the wide lateral spread of cassava roots plant density probably has little effect on N-recovery.
* Cultivation. The good results obtained with zero tillage and maintenance of crop residue were surprising to some participants.
* *Mucuna* seeds. As the short-cycle *Mucuna* used seems promising, farmers wanted to know how to obtain seed. Seed production is easier in a drier climate, such as E. Java, were seed for the project is bought. For use in the sugarcane plantation *Mucuna* seeds are produced locally as well. Small amounts of seeds are available from the project.
* Hedgerow intercropping may be a promising system for growing food crops at low rates of fertilizer application, but farmers would like to include fruit trees (Rambutan, Mangga, Blimbing, Melinjo); the consequences and management options have to be further investigated.
* *Albizia*/cocoa. Some farmers have a negative experience with *Albizia* as the

tree grown in-between cocoa. This may be attributed to the shallow root distribution of *Albizia* which we observed.

As the project is located on the terrain of a sugar-cane plantation various points were raised regarding the policies of the sugar factory:

* A number of questions were addressed to the Administrator of the sugar cane plantation regarding the policy (including a credit system) for stimulating transmigrant farmers to grow sugar cane on their plots.
* Because an organic waste product of the sugar refinery, blotong, can improve the soil in sugar cane plantations, farmers asked whether they could get part of the blotong in return for the sugar cane they deliver to the factory.
* Sugar cane/cowpea intercropping. Some positive experiences were reported with a cowpea intercrop between young sugar cane, similar to those obtained in an experiment of the N-project.
* Integration of animals. As some transmigrant farmers can build up their farm sufficiently to include some cows, integration of animals in, for instance, an alley cropping system becomes relevant. In view of its complexity this has not been included in the project as yet. Further research on decomposition of organic residues and wastes might include manure in the future.

If funds can be found to continue the project, in a next stage a further integration of extension and communication with farmers will be pursued. The main idea in this communication will be that no fixed 'recipes' exist, but that the way of analysing underlying processes as well as a number of the components tested in the experiments will be useful for farmers in improving their own cropping system.

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