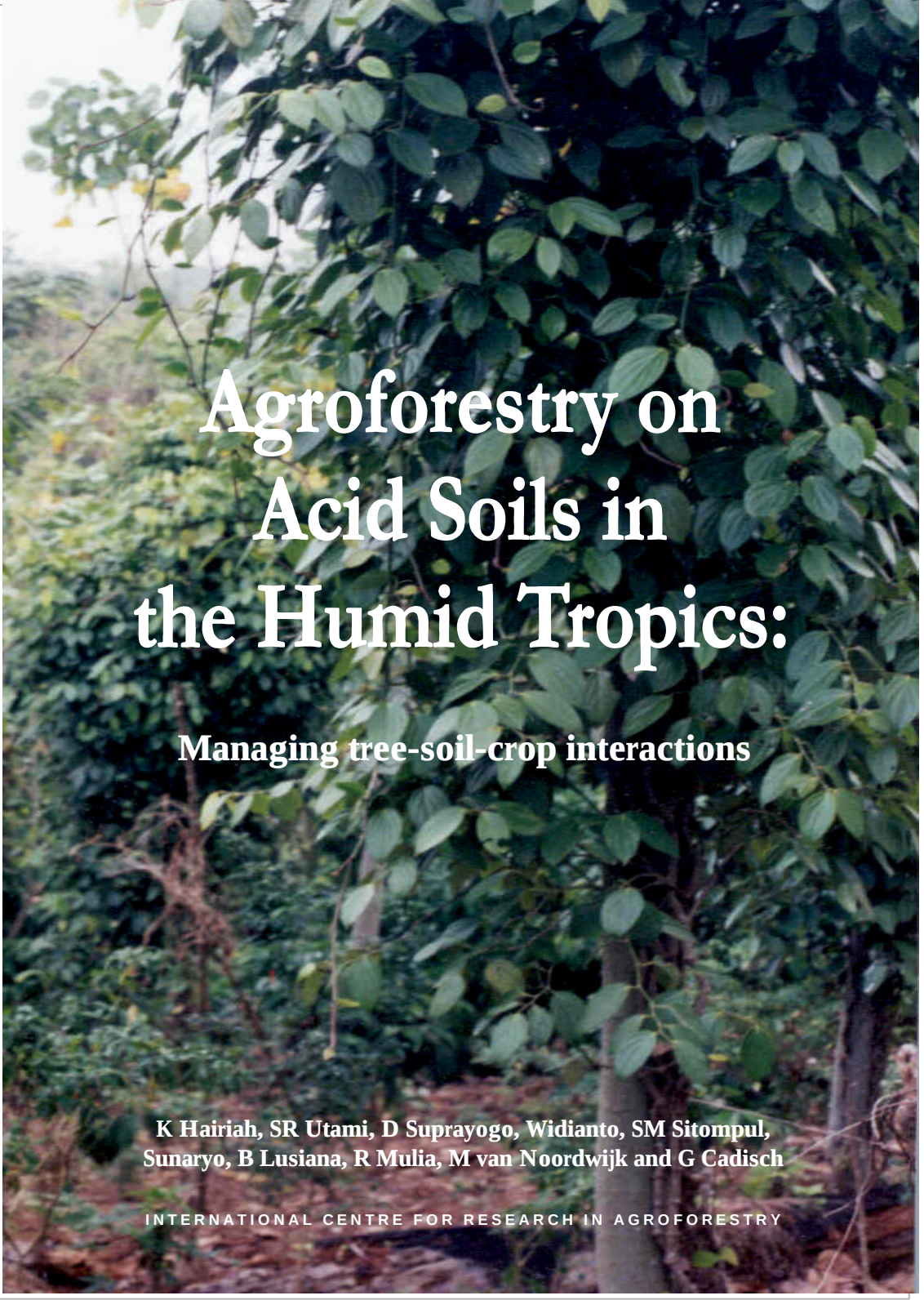


Agroforestry on Acid Soils in the Humid Tropics:

Managing tree-soil-crop interactions

K Hairiah, SR Utami, D Suprayogo, Widianto, SM Sitompul, Sunaryo, B Lusiana, R Mulia, M van Noordwijk and G Cadisch

INTERNATIONAL CENTRE FOR RESEARCH IN AGROFORESTRY

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Cover photos

front: Mixed garden in Northern Lampung: black pepper intercropped between fruit trees (durian, rambutan). *Erythrina* or *Gliricidia* are chosen as nurse trees, live poles, and green manure or sometimes as fodder.
(*taken by: Kurniatun Hairiah*)

back: Decaying tree root systems improve root growth of subsequent crops. Cassava roots growing in old tree root channels in an Ultisol.
(*taken by: Meine van Noordwijk*)

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Preface

Biological Management of Soil Fertility in the tropics, under high rainfall conditions, on acid soils. The objectives are easily stated – but implementation, for farmers who really have to make a living out there, is not so easy. In this brochure we summarize some key points that have emerged as part of a long term study in North Lampung (Sumatra, Indonesia). We hope that this description will be of use to. technicians, extension personnel, NGO's and local policy makers – who all try to help farmers in dealing with the hard realities. Sometimes, however, solutions that seem to be attractive from an outside perspective do not work out so well. Farmers, especially those coming from areas where soils are better and more fertile, have to learn fast, or otherwise move on to try their luck elsewhere. Researchers can learn a lot from farmers, their language and concepts – but hopefully in return they can offer some new insights as well.

This brochure marks the conclusion of an important phase in the Biological Management of Soil Fertility (BMSF) project in Lampung. Over the years, we have benefited from the experience and input of far too many people to mention them here. Let this be their anonymous acknowledgement.

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Farming on Acid Soils

-- How to make a living on a poor soil?

If the land is not productive it is hard to maintain a farming lifestyle. Farmers struggle to overcome agricultural constraints to maintain production, or adapt their choice of crops or trees to the realities of a place. On poor, acid soils as found for example in North Lampung (Sumatra, Indonesia), farmers try hard to improve and sustain crop production, by:



Photo 1. Mixed garden in North Lampung, consisting of coconut trees, cacao, *Gliricidia*, cassava, and chilli. (*photo: M. van Noordwijk*)

- ***Fallowing the land.*** After cultivating food crops for several seasons, farmers normally abandon their land for one or more years, and leave it for grass or shrubs to occupy. They expect that crop growth is improved, following the fallow period.
- ***Fertilization*** – as and when available and when the prices permit. Fertilizers commonly used are inorganic fertilizers (urea, ammonium-sulphate, TSP, and KCl) or organic fertilizers (compost, farmyard manure, crop residues, etc.).
- Using ***pesticides*** and ***herbicides*** to control pests, diseases and weeds.
- Growing crops on ridges can help ***control erosion***, especially on sloping land.
- ***Cropping system management***. Farmers know that soil fertility diminishes, when the same crop is grown continuously in monoculture. Therefore, crops that impoverish the soil, such as cassava, sweet potatoes or groundnuts (based on farmer experience planting a high yielding local variety, while removing the stover from the fields for use as fodder) have to be rotated with other crops. Intercropping, for example maize and rice, generates a higher income than the same crops grown as a monoculture.
- ***Crop selection***. If the soil can no longer support crops such as upland rice or beans, farmers may have cassava as the only remaining choice.

Realizing the benefit of trees and their higher tolerance of poor soil conditions, farmers also cultivate various perennial crops (trees) in their homegarden, as mixed tree plantation (Photo 1), or as farm border, especially on sloping land. Farmers start to plant economically valuable trees, such as rubber, oil palm and timber trees – but it takes time before one can benefit from trees. So, both trees and crops are seen as necessary to make a living on a poor soil.

-- working 'against' or 'alongside' nature

The basic choice is between struggling against the odds and trying to control natural processes of degradation when growing annual food crops or plantation-style monocultures of trees, or going with the flow and allowing woody vegetation to develop in the form of an agroforest (see below) with as many useful components as possible. The choice involves culture, tradition and knowledge of the outcomes that can be expected....

Managing Acid Soils for Annual Food Crops

-- why is it that farmers remain empty-handed?

Many limiting factors are responsible for a low production potential in an area such as Pakuan Ratu District in the northern part of Lampung. The soils are *Ultisols*, poor in soil organic matter and nutrients such as P (phosphorus), with a low cation exchange capacity and high Al (aluminium) toxicity in lower soil horizons. These soils store only a limited amount of water. On such a soil many crops remain shallow rooted and sensitive to drought, even when the rainfall brings more than 2 m of water per year, or twice as much as plants can use. Irregular droughts during the cropping season can cause crop failure and years with long dry seasons can devastate tree crops that are not adapted to drought.

Recently, transmigrant farmers from Java became interested in planting fast growing timber trees such as *Paraserianthes falcataria* and *Acacia mangium*. Based on their experience in Java, they planted *Paraserianthes falcataria* (sengon) in great numbers, although the species grows poorly especially on the poorer uphill sites. Photo 2 shows many of the *Paraserianthes* died off during a long dry season. The poor growth of

Paraserianthes during the dry season might be due to a shallow root system. Inhibition of root growth in acid soils is usually caused by Al toxicity, but other soil chemical or soil physical factors, such as mechanical impedance or poor aeration might be involved as well.



Photo 2. *Paraserianthes*, a fast growing tree species that is susceptible to drought on acid soils. *(photo: Kurniatun Hairiah)*

In the past, when the land was still covered by natural forest, these limiting factors were not detected and the lush forest seemed to promise good conditions for agriculture. Natural forest has a *closed nutrient cycle*, meaning that nearly all nutrients taken by vegetation from soil or decomposing litter are eventually returned to the soil through litter fall. Nutrient losses through leaching and erosion are negligible in this system, and much of the nutrient capital becomes stored in the aboveground vegetation.





Photo 3. Cassava in Lampung: stress on infertile soils. The land surface is exposed to the direct impact of the sun and rainfall, leading to loss of soil structure. *(photo: Kurniatun Hairiah)*
Photo 4. Effective soil management on these eroded soils is difficult, but notice the farmer's attempt to reclaim eroded gullies by growing pineapple. *(photo: Kurniatun Hairiah)*

When natural forest is destroyed and the land converted to agriculture by slash-and-burn or bulldozer clearing, most of the nutrient capital of the forest is lost. Also, other soil characteristics change rapidly. The closed nutrient cycle of the forest becomes an *open nutrient flow*, reflected in an increasing imbalance between nutrient uptake and return to the soil. For example: after 3-5 years of forest being converted to crops and eventually to cassava, the soil becomes white and hard (Photo 3). This is because most of the biomass produced is exported from the land with the harvested products, especially when crop residues or stover are removed as fodder. The soil organic matter content, which is important for the water and nutrient holding capacity, declines with time. The land surface in agriculture is generally more exposed to the direct impact of sun and rainfall, leading to loss of soil structure. Once water cannot easily infiltrate into the topsoil, it starts to flow over the soil surface and this leads to erosion and loss of nutrients from the plot (Photo 4). Also, for reasons explained below in more detail, nutrients can leach out of the soil and into the groundwater more easily in a cropped field than under a forest. Removal of harvested products, movement of fertile topsoil out of the field with erosion and leaching all increase nutrient losses. As a result, soil fertility declines rapidly.

Diminishing soil fertility is easily recognized in the field. For instance, food crop yield decreases year after year. The amount of fertilizer that has to be applied to maintain yield increases with time. For many crops the use of fertilizer does not really pay off any more, farmers have to resort to the crop that is best in mining the remaining fertility out of the soil: cassava. But even the cassava will remain small and in the open spaces alang-alang (spear grass or *Imperata cylindrica*) gets a chance to take over.

In the tradition of shifting cultivation, land was abandoned after being used for crop cultivation for a few years and before all tree stumps had died. A new patch of land was cleared for agriculture and woody vegetation could rapidly take over the previously cropped field. If not enough land is available, however, the fallow cannot fully restore soil fertility for the next cycle and cropping may continue so long that the tree stumps die and the next fallow is dominated by grasses such as alang-alang (*Imperata cylindrica*). This happened in government resettlement ('transmigration') schemes where the farmers did not get enough land to allow for a sufficient length of fallow. It also happened where

spontaneous migrants could only afford to buy a limited amount of land from the people who previously used the land for long-cycle shifting cultivation.



Photo 5. Alang-alang infested land: watch out for fire! *(photo: Meine van Noordwijk)*

Once alang-alang had taken over, the fallow lands became difficult to recover for growing crops, even if herbicides were used. In alang-alang grassland fire spreads easily in the dry season, killing many young trees (Photo 5). The grass, however, survives in its rhizomes well below the soil surface and re-sprouts quickly after a fire. So, fire tends to perpetuate the grassland and slow down the development of forest cover. Clearing alang-alang grasslands is also complicated by the rhizomes that survive soil tillage and regrow. A repeated cycle of soil tillage is needed to reduce the vigour of the rhizomes. Farmers prefer herbicide as a method for alang-alang control, if they can afford it. Herbicide is more effective on regrowing young shoots than on a well-established stand, so initial clearing or the use of fire is still needed. Fire can escape to neighbouring lands and can lead to social conflict. Alang-alang is well adapted to poor soils, but it has only a limited positive effect on soil fertility as a fallow vegetation. If grasslands are frequently burned, soil fertility declines and there is no positive 'fallow' effect at all, so the farmer who struggled to reclaim the grassland for another cycle of crops will remain empty-handed.

Farmers know that cassava exploits the soil and mines the remaining nutrients efficiently. Still, they tend to plant cassava. There is little choice for them, as few other crops are adapted to drought and infertile soils. When asked, farmers in north Lampung explain their decision to plant cassava as follows:

- Planting material is readily available from the stems of a previous crop
- Cassava requires little care: it is rarely attacked by pests, is resistant to drought, and is suitable for poor soils; the main pests of cassava are the wild pigs that roamed the area when there were still remnants of forest -- now that the forest and the pigs are gone, cassava is safe

- Cassava can still grow without fertilizer, although it responds positively when fertilizer is applied
- Cassava is flexible: it can be planted almost throughout the year and the harvest time can be adjusted in response to labour supply and price fluctuations
- There are several cassava processing factories in the area and the procedure of selling cassava tubers to the factories is simple; the price obtained, however, depends on the 'quality' of the tubers and is based on measurements that the farmers cannot fully understand or check themselves.
- If rice or maize fail, cassava can still be used as food for the family, although the varieties used have a high cyanide content and need special processing.

The price of cassava, however, goes up and down, as it is determined by the world market for fodder and there is little a farmer can do other than accept that some years the revenue pays back the labour invested, but in other years it does not.

-- using fertilizer to overcome low soil fertility

Inorganic fertilizers containing N (nitrogen), P (phosphorus) or K (potassium) can be used as rapid and easy amendments of nutrient deficiency -- but they are costly and their use is only justified if the nutrients are taken up efficiently by crops of sufficient value. However, on acid soils with low pH and high Al toxicity, phosphorus is bound by the soil and is poorly available to crops. Nitrogen fertilizer is subject to rapid leaching, especially where crop roots only can grow in the shallow topsoil. Because of the low cation exchange capacity potassium is lost easily.

To make fertilizer application more efficient, several points have to be considered in the method of fertilizer application:

- Time of application: Fertilizer application should be timed to coincide with crop demand, in what is called *synchronization* (Figure 1). N fertilizer should be split over several applications, in accordance with the crop growth cycle. The standard Indonesian recommendation of 50% at crop planting and 50% after 30 days is better than giving all the

fertilizer at once, but still can not prevent losses from the soil. A more refined application scheme needs local adjustment. For example growing maize in N. Lampung, farmers usually apply 45 kg N ha^{-1} of urea at planting time and the other 45 kg N ha^{-1} at 4 weeks after planting.

- Fertilizer placement: Ideally, fertilizer should be placed in a zone of high root activity ('*synlocation*') where it is protected from leaching, but in a zone that is neither too wet nor too dry, so that it can be effectively absorbed by roots. In practice this is not easily achieved. If crops are grown on ridges, then a position halfway up the ridges may be best.
- Fertilizer balance and application rate: The amount of fertilizer applied for each nutrient should match the part of the nutrient demand of the food crop that cannot be supplied by the soil. Fertilizer application that does not achieve such a balance between the nutrients can be ineffective. This is actually a common occurrence when farmer decisions to apply fertilizer are limited by cost and availability of the fertilizer, rather than by detailed knowledge of the soil fertility.
- Controlling acidification of the soil: When ammonium sulphate is used as source of nitrogen, the soil will become more acid (lower pH). The same happens, but more gradually, when urea is used. In the long term, lime or a similar basic reacting material is needed to counteract this acidification. In acid soils rock phosphate, rather than the chemically processed TSP, can effectively be used as source of P as well as to supply calcium.

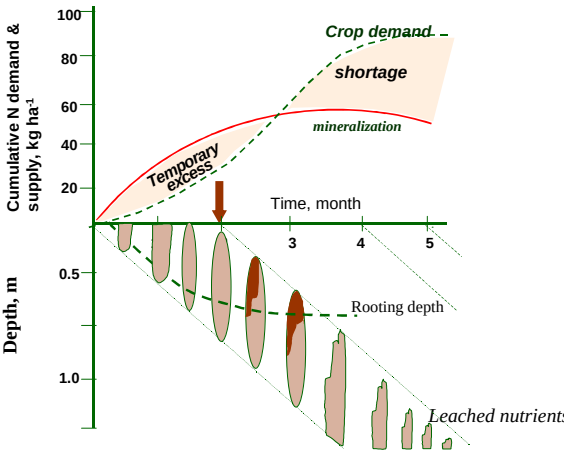


Figure 1. Schematic presentation of incomplete synchrony of mineralization and crop demand for nutrients such as N and the ensuing infiltration pattern in a high-rainfall climate. Recovery by the crop in a later part of the growing season, when crop demand exceeds mineralization, depends on rooting depth.

Inorganic fertilizer by itself cannot stop soil physical degradation or erosion, but it can lead to better crop cover and more crop residues that can provide organic matter to the soil, if managed properly.

-- keeping the soil 'cool': farmer notions of soil fertility

Farmers in Lampung have learned to value dark coloured soil, rich in organic matter. Such a soil is considered 'cool', in contrast to the 'hot' soil that has been exposed to the sun and to degradation. 'Cool soil' is a fertile soil, easy to till, and always moist and favourable for plant growth (Photo 6). To keep a soil 'cool' it should have a litter layer on top of the mineral soil, just as happens in a forest.



Photo 6. Dark coloured soil, rich in organic matter: moist soil. (*photo: Meine van Noordwijk*)

The farmers notion of soil 'coolness' can be directly related to the organic matter functions in the soil (supplying nutrients, increasing soil cation exchange capacity and increasing water holding capacity, aggregate stability and porosity), that guarantee water and air flows ('diffusion') within the soil. Improvement of soil properties by organic matter indirectly decreases erosion and nutrient leaching. Organic matter can also alleviate Al toxicity in the soil.

Farmers know that a 'cool' soil is desirable. But keeping a soil in that condition is not easily combined with growing food crops, especially if soil tillage is used to control weeds, or make a seedbed for the crop. Soil tillage will destroy the protective litter layer on top of the soil. To keep the soil undisturbed a 'no-till' system where crops are established by dibbling seeds into holes -- a traditional planting system for 'shifting cultivators' but now often replaced by more intensive soil cultivation – can be applied.

-- how to increase soil organic matter?

Soil organic matter occurs in different forms: some stable and closely linked to clay particles in the soil, forming stable aggregates, others in various stages of decomposition still related to their origin of dead leaves, woody stems or roots. A (secondary) forest soil receives 10 - 12 ton per ha every year of litterfall on its surface, plus the deposits of decaying roots. In a cropping system one should aim for at least 8 ton/ha of organic inputs to keep the soil organic matter close to the target value (say, 80% of forest SOM at the same soil texture).

Farmers can try to achieve this by:

a) Keeping ***plant residues*** in the plot (maize or rice) or returning them (groundnut), depending on the crop harvesting practice. Such crop residues can amount to 2-5 ton per ha per crop -- not enough by themselves but an opportunity not to be missed. With cassava, however, the stems are normally removed at harvest (Photo 7) to be used as planting material elsewhere, and the only input to the soil for a whole year is 1 ton per ha of litterfall.

b) Applying farmyard ***manure*** or ***composted organic waste*** from the kitchen and household. In practice, however, the limited supply of manure is mostly used in the homegarden and on high-value vegetable crops, not on fields away from the homestead.

c) Use of ***cover crops*** (Photo 8) for the off-season after the main food crop is harvested. In years with adequate rainfall, a legume cover crop ('LCC') will produce a biomass of 2-3 ton per ha in 3 months time or 3-6 ton per ha if left for 6



Photo 7. Cassava monoculture gives a negative nutrient balance: most biomass is removed from the plots. (*photo: Kurniatun Hairiah*)

months. The labour and seed cost involved in this does not directly pay off, however. The best chances are still with legume cover crops that

- become self-seeding in the plot and can be prevented from becoming a weed in the cropping season (*Calopogonium*), or
- have some direct value from edible seeds (*Mucuna pruriens* var *utilis*, Ind: koro benguk) but still leave a large leafy biomass.



Photo 8. The legume cover crop *Mucuna* is capable of shading out *Imperata*, unfortunately its short life cycle allows *Imperata* rhizomes to regrow: organic matter supply of *Mucuna* amounted to 2-6 ton/ha. (*photo: Kurniatun Hairiah*)

d) Using ***litter*** produced by trees growing close to the cropped field, either on the field boundary, or in hedgerows in the field itself, but coppiced or pruned while crops are grown. With this 'agroforestry' technique it is possible to get enough organic inputs to the soil - but there are other problems (see below).

Making the Transition to Tree Crops and Agroforests

-- not all trees are the same

Farmers know that the supply of organic matter to the soil under a natural forest can restore soil fertility. It is a small step to then consider how trees planted deliberately can sustain soil fertility, or even restore degraded soils. But, trees use space, light, water and nutrients, so trees that produce valuable products are preferred. Farmers in north Lampung give the following reasons for planting trees on their own land:

- Trees provide a nearby stock of firewood and timber; these are no longer easily available elsewhere in the landscape as the forest has been depleted and are becoming expensive. (Photo 9)
- Trees (fruit and timber types) generate an accumulated high income, providing a savings account for children and grandchildren

- Trees do not need intensive management, saving farmers' time and budget
- Young trees do not restrict crop growth, but can even help in protecting the soil
- If the trees grow up and give shade, the remaining land can be used for crops adaptable to shade, such as cocoyam (Ind: talas, *Colocasia esculenta*), turmeric (Ind: kunyit, *Curcuma domestica)*, and medicinal plants for daily use.



Photo 9. The availability of firewood is becoming low in Pakuan Ratu (Lampung) since a large area has been invaded by *Imperata*. During the dry season *Imperata* fields easily catch fire. (*photo: Kurniatun Hairiah*)

Several other considerations influence farmers' decision whether or not to plant trees. Many farmers are still oriented to cultivate food crops. For food crops, farmers can get the product in a few months, whereas for trees, farmers have to wait for a long time before they benefit. Seedlings, for example of good quality fruit trees, are also difficult to obtain, and if they are available, they are too expensive for farmers.

The best choice for making the transition probably is intercropping food crops with economically valuable trees. However, farmers are still cautious that trees compete with crops. Tree selection is still an unsolved problem for farmers. They have seen failure of many trees in years with a long dry season: hybrid coconut died off, *Paraserianthes falcataria* (sengon) suffered severely (Figure 2), oil palm got burned and took time to recover (Figure 11). The duku (*Lansium domesticum*) trees that used to be common in the old homegardens of traditional Lampung villages dies in the drought, probably after they had become too exposed as upper canopy trees. Unsuitable trees, which are incorporated to mixed cropping, together with improper management may result in production failure or further soil degradation.

Several other considerations influence farmers' decisions on whether or not to plant trees. Many farmers are still oriented towards cultivating food crops. For food crops, farmers can get the product in a few months, whereas for trees, farmers have to wait for a long time before they benefit. Seedlings, for example of good quality fruit trees, are also difficult to obtain, and if they are available, they may be considered to be too expensive for farmers.



Photo 10. Accidentally burned oil palm takes a long time to recover after fire. (*photo: Meine van Noordwijk*)

The best choice for making the transition is probably intercropping food crops with economically valuable trees. However, farmers still worry that trees compete with crops. Tree selection is still an unsolved problem for farmers. They have seen the failure of many trees in years with a long dry season: hybrid coconut died off, *Paraserianthes falcataria* (sengon) suffered severely (Photo 2), oil palm got burned and took time to recover (Photo 10). The duku (*Lansium domesticum*) trees that used to be common in the old homegardens of traditional Lampung villages died in the 1997 drought, probably after they had become too exposed as upper canopy trees. Unsuitable trees, which are incorporated into mixed cropping systems, together with improper management may result in production failure or even in further soil degradation.

-- simple or complex agroforestry systems?

Agroforestry can be simply defined as incorporating trees into agricultural land. There are two basic forms of 'agroforest' (De Foresta et al., 1997), simple and complex:

- *Simple agroforests* result from the introduction of trees to mixed cropping systems with one or more seasonal food crops. This system is common in Lampung. Farmers practice intercropping between rubber

and cassava (Photo 11), *Paraserianthes falcataria* with cassava (Photo 12), rubber with bananas, papaya, and rice (Photo 13). Trees are often planted in rows, and the alley between rows is used for food crops (alley cropping or hedgerow intercropping). However it is more common to find trees at the borders of fields. For example *Leucaena* with rice or maize, coconut trees surrounding irrigated rice fields, etc. Another example is a well established mixed garden with 'black pepper' which is valued for its economic products (both black and white pepper, depending on the ripeness when picked) and for its low labour requirements. This type of pepper cropping is commonly practiced by farmers originating from Lampung. Other fruit trees e.g. durian, *Parkia* or other timber trees are often grown on the same land. *Erythrina* (Ind: dadap) or *Gliricidia* (Ind: gamal) are chosen as nurse trees and as live poles (Photo 14).



Photo 11. Rubber and cassava intercropping system: an example of a simple agroforest commonly practiced in Lampung. Farmers have realised that this intercropping system with two plants from the same family may favour diseases in rubber, but how else can their family survive?
(*photo: Kurniatun Hairiah*)



Photo 12. *Paraserianthes falcataria* (Ind: sengon) intercropped with cassava in Pakuan Ratu.
(*photo: James Roshetko*)

- *Complex agroforests* look and function more like a natural forest and have a complex vegetation structure, with a high number of components, such as trees, shrubs, lianas, grasses, herbs, and annual crops. Some of the components are planted by the farmer, others grow spontaneously from seed or stumps and are tolerated or managed. *Tree dominated homegardens* are normally found around the house and are usually small (0.1-0.3 ha) (Photo 15). Outside the village, *complex agroforests* look like a 'forest mosaic', although they are composed of many small plots of 1 to 2 ha which are individually owned and managed. Examples are the 'jungle rubber' gardens (Photo 16) which cover much of Sumatra's lowland peneplains, the damar gardens of Krui in West Lampung or mixed fruit tree gardens.



Photo 13. Mixed cropping commonly occurs in farmers' fields after slashing and burning of forests, combinations of rubber, banana trees, papaya and rice are planted. (*photo: Kurniatun Hairiah*)



Photo 14. Black (white) pepper is commonly cropped by farmers who originate from Lampung. *Erythrina* or *Gliricidia* are chosen as nurse trees and as live poles. *Gliricidia* is ideal for live poles due to its upright branches. (*photo: Kurniatun Hairiah*)



Photo 15. Homegarden in Pakuan Ratu containing rambutan, *Gnetum gnemon* (Ind: blinjo), banana, coconut and *Gliricidia* (Ind: gamal). The understorey consists of annual crops such as cocoyam, turmeric, lemon grass etc. (*photo: Meine van Noordwijk*)

The management of these two types of agroforests differs in intensity -- the complex agroforests more truly represent the ideal of 'working along with nature', but it takes longer to get them productive. The boundary of the two is not sharp. The damar agroforest starts off as an intensively managed coffee system with fruit and shade trees, where eventually the damar trees get the upper hand.



Photo 16. Jungle rubber is commonly practiced by farmers in Sumatra's lowland peneplain. It has a complex vegetation structure, with a high number of components: various trees (mainly rubber), shrubs, lianas, ferns, herbs. This photo shows a young state. (*photo: Meine van Noordwijk*)