Why alley-cropping with fast growing legume trees has not lived up to the expectations

The idea was so nice. Growing trees in hedgerows in between the crop fields, the farmers might have the best of two worlds: little interference with the crops during the cropping season when the trees were to be pruned back, and a continuous supply of organic inputs by litterfall from the trees and in the form of pruned branches. Where mulch transfer from outside the field is difficult and labour intensive, prunings from the hedgerows could be left approximately where they fell. The idea of thus combining the tree functions of a 'fallow' with the more intensive use as crop land was attractive, and many research and development agencies jumped at the opportunities that 'alley-cropping' or 'hedgerow intercropping' seemed to promise in the 1980's.

In practice, however, managing the trees proved to be more difficult than expected, especially in the case of fast-growing trees, that quickly recovered from pruning. A single pruning operation cost some 20-30 person days per ha, and when you consider that it is necessary to prune 2 to 3 times per year, this is simply too much. Pruning the trees at the start of a crop may be difficult, as this is a busy time for the farmer. However, the shade from the trees may have reduced the weediness of the field and probably saved the farmer some time in land preparation.

Experience in a long term (1986 - 1999) experiment with alley-cropping on an acid soil in North Lampung at the Biological Management of Soil Fertility (BMSF) research site has shown disappointing results for all fast-growing leguminous trees that are normally recommended. Even with a lot of pruning, these trees proved to be too competitive. Better results were obtained with the local tree *Peltophorum dasyrrachis* (Ind: petaian) that is deeper rooted, has a denser but narrower tree canopy that recovers well from regular pruning and is slow growing and thus has to be pruned less.

-- tree-soil-crop interactions

Understanding tree-annual crop interactions strongly determines the results of the transition into agroforest: success or failure! The overall interactions can be positive (advantageous) or negative (disadvantageous) (Figure 2).

Disadvantageous interactions

- Competition for light: shading by trees, reducing light intensity at crop level
- Competition for nutrient and water: shallow tree root systems are likely to compete with crops for nutrient and water, reducing uptake by crop roots.
- Trees can be a host for pests and diseases of annual food crops (or vice-versa).

Advantageous interactions

- Litter fall and pruned leaves or small branches supply a protective litter layer and organic matter for the soil
- A litter layer reduces loss of water from the soil surface by evaporation and improves the soil moisture regime
- Shading by trees may suppress weed growth (e.g. *Imperata cylindrica*), and reduce the risk of fire spread in the dry season
- Deep tree rooting systems improve nutrient recycling by acting as a (1) *nutrient safety- net*, taking up nutrients which leach out to the subsoil, out of reach for the shallow rooted crops; and (2) *nutrient pump*, taking up nutrients released from mineral weathering in deeper layers
- Legume trees can biologically fix nitrogen from the atmosphere (N_2), and supply nitrogen to the soil that decreases the requirement for N fertilizer
- Providing a stable microclimate, by reducing wind speed, increasing air humidity, providing partial shade (for instance *Erythrina* in cacao or coffee gardens)

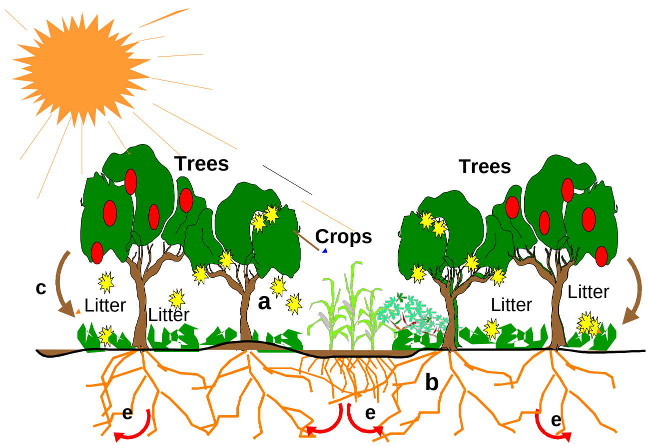


Figure 2. Interaction between trees and crops in a simultaneous agroforestry system (a= shading; b= competition for water and nutrient; c= litterfall increases soil organic matter and nutrient; d= deep rooted trees play a role as a 'safety net' for leached nutrient in the deeper layer).

- Giving long-term benefits, i.e. reducing risk of erosion through improved soil structure and porosity by the addition of organic matter.

The key for the success of agroforestry practice strongly depends on how well you minimize the disadvantageous effects and maximize the advantageous effects (of course at an acceptable level of labour input).

Minimize disadvantageous effect

- Shading effects can be reduced by regularly pruning during the cropping phase,
- Selecting trees with a rather narrow but dense canopy to reduce competition for light,
- Widening tree spacing, to reduce aboveground competition, as well as belowground competition,
- Selecting shade tolerant crops, such as cocoyam, ginger, etc.
- Selecting deep rooted trees, to avoid competition for water and nutrients,
- Creating a suitable tree distance, wide enough to avoid strong competition with crops, but close enough to control weeds, and to get maximum benefits from the organic matter supply.

Maximize advantageous effect

Selecting a suitable tree for mixed cropping with annual crops, on the basis of:

- Canopy shape and distribution: A tall tree with a relatively dense but narrow canopy will not give too much shade to the crop (Figure 3) during the cropping season. By contrast, trees with a spreading half-open canopy may allow light to reach the crops, but they are unsuitable for controlling invading weeds after or in-between the cropping periods
- Quality and quantity of the organic matter supply: To maximize the positive effects, trees with slow-decomposing litter are to be combined with trees with fast-decomposing organic residues. Litter of low 'quality' decomposes slowly and is suitable for mulch, protecting the soil surface from erosion. In contrast, litter of high quality will decompose rapidly, and so leach easily. High quality litter has potential as nutrient supply for crops. Combination of low quality and high

quality litters may increase synchronization of nutrient release from organic residues with crop demand

- Growth ability: Suitable trees for mixed cropping have to grow rather slowly at the beginning of a cropping phase, but survive (resist fire) in the dry season
- Rooting depth and distribution. Trees with a deep and well-distributed rooting system will decrease nutrient leaching (Photo 17).
- Survival of regular pruning. Pruning is absolutely necessary to avoid excessive shading. However, there are trees which do not survive (repeated) pruning.
- Resistance to pest and diseases
- Capacity for biological N_2-fixation

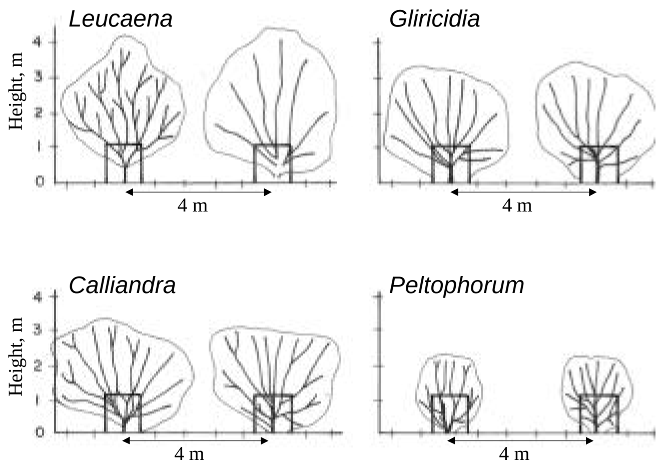


Figure 3. Canopy shape of various trees in hedgerow intercropping systems in Lampung (Hairiah et al., 1992).

Photo 17. The shallow rooting system of *Leucaena* causes competition for nutrients and water with maize roots (top). The deep rooting system of *Peltophorum*, leads to less competition, and reduces N leaching (below). (*photo: Pratiknyo Purnomosidhi*)

Table 1 presents canopy shape and root depth of various trees, that farmers may wish to plant. An overall evaluation for the suitability of trees for intercropping with annual crops is presented in Table 2.

Table 1. Rooting depth and canopy shape of trees with potential for mixed cropping

Tree	**Rooting depth**	**Canopy shape***
Leucaena leucocephala	Shallow	Scattered, needs 3-5 prunings per year
Calliandra calothyrsus	Moderate	Scattered, needs 3-5 prunings per year
Gliricidia sepium	Shallow	Scattered, needs 3-5 prunings per year
Erythrina orientalis	Moderate	Scattered, needs 3-5 prunings per year, but rather sensitive to pruning
Peltophorum dasyrrachis	Deep	Narrow and dense, concentrated in the middle (narrow), maximum pruning 3x per year
Peronema canescens	Very shallow	Narrow and thin
Pithecellobium jiringa	Shallow	Intermediate
Parkia speciosa	Shallow	Scattered
Paraserianthes falcataria	Shallow	Scattered
Psidium guajava (Guava)	Shallow	Intermediate
Gnetum gnemon	Shallow	Narrow and thin
Ceiba pentandra (kapok)	Deep	Scattered
Anacardium occidentale (cashew-nut)	Deep	Intermediate
Artocarpus heterophyllus (jack fruit)	Very deep	Intermediate
Mangifera indica (manggo)	Very deep	Intermediate
Durio zibethinus (Durian)	Very deep	Intermediate

*) Canopy shape (refer to examples in Figure 3)

- Scattered, similar to canopy shape of *Leucaena* , *Gliricidia* and *Calliandra*
- Narrow and dense, similar to canopy shape of *Peltophorum*
- Narrow and thin, similar to canopy shape of *Peltophorum* but with less dense shoots biomass
- Intermediate, something in between scattered -narrow and -dense

Table 2. Overall evaluation of the suitability of trees for intercropping (Hairiah *et al*., 1992)

Species	Below ground				Above ground							
	Root depth	Root horiz.	Nodulation	Mycorrhiza	Organic Matter input	N-input	Decomposition rate	Pruning need during crop phase	Imperata control	Fire wood quality	Fire wood quantity	Browse quality
Leu	1	2	0/+	?	8	190	F	Yes	0	+	+	+
Glir	1	3	+	+	8	230	VF	Yes	0	+	+	+
Cas	2	2	0	+	8	- ?	F	Yes	+	+	+	?
Cal	1	3	+	+	12	360	M	Yes	+	-	+++	+
Ery	2	1	+	+	4	110	F	No	-	+	+	?
Alb	1	3	+	+	*	*	M	*	-	+	+	?
Per	1	2	0	?	*	*	VS	*	?	+	?	?
Pel	1/2	1	0	+	8	170	S	No	+	+	+	+

Note:

- Leu = *Leucaena*; Gli = *Gliricidia*; Cas = *Cassia*; Cal = *Calliandra*; Ery = *Erythrina*; Alb = *Albizia* (or *Paraserianthes falcataria)*; Per = *Peronema*; Pel = *Peltophorum*,
- Root depth = rooting depth, if there is no pruning: 1: concentrated in topsoil (0-20 cm); 2: few roots in 20-60 cm; 3: relatively deep (>60 cm) rooted,
- Root horiz. = roots in the surface horizon, among crop roots: 1 : few; 2 : many; 3 : very many,
- Nodulation: 0 : none; +: few; ++: many,
- Mycorrhiza: mycorrhiza infection (percentage of roots): +: 5-15%; ++: 25%,
- Organic matter input = biomass production (ton ha^{-1}) per year (leaves and small branches), regularly pruned, with 4m interrow distance; * no data available
- N input (kg per ha per year), if regularly pruned, * no data available
- Decomposition rate: Decomposition rate judged from litter quality; VS: very slow; S: slow; M: moderate; F: fast; VF: very fast
- Pruning required = second pruning required to avoid excessive shading during maize/soybean growing season; yes: necessary; no: unnecessary, * not applicable,
- *Imperata* control: ability to control *Imperata* (alang-alang), if left unpruned for 8 months: 0 = moderate + = good, - = poor
- Firewood quality: *Calliandra* easily burnt, unsuitable for firewood
- Firewood quantity if unpruned for 8 months
- Browse quality: browse quality for goats; 0: uneaten; +: only young leaves eaten; ++: all young and old leaves eaten

Box 1:
Case-study on N leached in a hedgerow intercropping trial

Figure 4 shows the effectiveness of different cropping systems in reducing water drainage, concentration, and amount of mineral N leached below 0.8 m soil depth. Water drainage was similar in all cropping systems of this experiment at the BMSF site in Lampung, but on some occasions it was lower in monoculture than in hedgerow intercropping systems. Mineral N contents in the soil solutions extracted from ceramic cups over the duration of the water balance measurements indicated that there was greater accumulation towards the end of maize and groundnut growth than during other sampling periods. Under maize-groundnut, the mean (minimum-maximum) concentration of mineral N content declined in the following order; monocropping system (7.3 (2.6-17.3) mg l^{-1}) > *Gliricidia* hedgerows (6.9 (2.8-19.7) mg l^{-1}) > alternating *Peltophorum* and *Gliricidia* hedgerows (6.9 (2.4-22.9) mg l^{-1}) > *Peltophorum* hedgerows (2.0 (1.0-3.9) mg l^{-1}). The minimum and maximum amount of mineral N leached during each interval differed widely in the following order; *Gliricidia* > maize-groundnut monoculture > alternate *Peltophorum* and *Gliricidia* hedgerow intercropping system and > *Peltophorum* hedgerow intercropping system. The *Peltophorum* hedgerow intercropping system significantly reduced the cumulative amount of leached mineral N by 45 kg N ha^{-1} in comparison with the control (Table 3) but the hedgerow intercropping system with *Gliricidia* did not.

Table 3. Effect of hedgerow intercropping systems and type of nitrogen input on cumulative amount of mineral N leached below 0.8 m depth determined using vacuum lysimeter under maize – groundnut rotation (Suprayogo *et al*., 2000). (PP = *Peltophorum* hedgerow, GG = *Gliricidia* hedgerow, PG= alternate *Peltophorum* and *Gliricidia* hedgerow intercropping system, C = Control, annual crops monoculture)

Cropping systems and treatments	Cumulative mineral N (NH_4^+ -N + NO_3^--N) leached		
	Maize cycle	Groundnut cycle	Maize + groundnut cycle
	kg ha^{-1} (%[1])		
PP + 90 kg N ha^{-1}	17.0 (-68)	3.1 (-75)	20.1 (-73)
GG + 90 kg N ha^{-1}	47.3 (-11)	16.5 (+33)	63.7 (-3)
PG + 90 kg N ha^{-1}	46.3 (-12)	13.7 (-10)	60.0 (-8)
C + 90 kg N ha^{-1}	53.0 (0)	12.4 (0)	65.4 (0)
SED	5.8	0.9	5.9
F pr.	<0.05	<0.05	<0.05

[1)] Percentage (–) decrease or (+) increase of total leached mineral N.
SED = standard error of difference of means.

Box 1. Case study (continued)

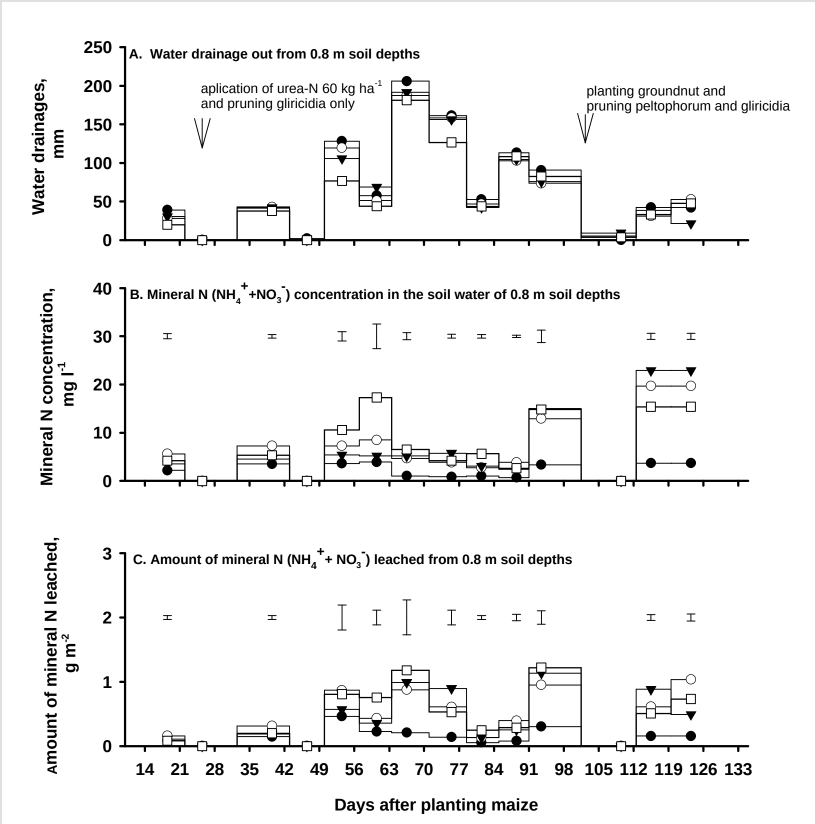


Figure 4. Vertical water drainage, mineral N concentration, and amount of leached mineral N from 0.8 m soil depth. (•) = *Peltophorum* (o) = *Gliricidia*, (▾) = alternate *Peltophorum* and *Gliricidia* hedgerow intercropping systems and (?) = monoculture cropping systems with 90 kg N (urea fertiliser) ha^{-1}. Error bars represent standard error of difference of means (Suprayogo *et al*., 2000).

Water, nutrient and light capture in agroforestry systems (WaNuLCAS)

-- Can we predict the balance between positive and negative interactions?

Agroforestry involves: many possible tree and crop components, many ecological interactions, many management options, many possible objectives and targets, long term impacts on soil quality, quality and quantity of water that flows to neighbouring plots and streams. We cannot measure them all or do detailed experiments to develop recommendations, in contrast to paddy rice monoculture. Decisions by farmers have to be made on the basis of a more global understanding of what goes on and the consequences of various management options.

We think that more than a century of research on how crops and trees grow, on processes in the soil, and their interaction with climate has led to a recognition of some important basic principles that apply in agroforestry – see above. But, we recognize that many of these factors interact in a way that goes beyond what we can cope with by just thinking or using a pencil and a piece of paper and making a diagram. For example: leaching of N depends on the degree of 'synchrony' of demand and supply of mineral N, but also on the amount of water that infiltrates into the soil from rainfall or from overland flow from plots uphill. The more water a crop or tree uses in between rainfall events, the more water can be stored back into the soil from a rainfall event before the surplus will leach down. So the need for 'synchrony' depends on the water use of the vegetation in relation to rainfall and rooting depth. We may understand the principles involved, but need some help in relating all these processes to a final outcome. To help us in piecing together such information, 'simulation models' have been developed that do just that: describing the various processes in what seems to be an acceptable level of accuracy (not oversimplifying, but also not using excessive detail), and working out the logical consequences to predict what the outcome will be.

As agroforestry systems are complex, the simulation model also may have to consider many types of processes. We will here give examples from the WaNuLCAS model that was designed to provide a synthesis of our current understanding of water, nutrient and light capture in agroforestry systems (Figure 5). The model represents a 4-layer soil profile with water N, P and C balance. Water and nutrient uptake by crops and trees is based on their root length densities and current demand. The model allows for the evaluation of different pruning regimes, hedgerow spacing, choice of species or provenance and fertilizer application rates. It includes various tree characteristics such as root distribution, canopy shape, litter quality, maximum growth rate and speed of recovery after pruning. The model can also be used for both simultaneous and sequential agroforestry systems (e.g. fallow – crop rotation) and may help researchers understand the continuum of options from improved fallow relay planting of tree fallows to rotational and simultaneous forms of hedgerow intercropping.

The first type of use of such a model is as an aid in 'diagnosis', in formulating hypotheses about what goes on in a specific location, given its climate, soil, crops, trees, weeds and farmer management decisions. That's a huge task by itself. We need experimental data to check whether the model does indeed make reasonable predictions by applying it to a situation where we know the outcome. The data of Box 1 give us such an opportunity.

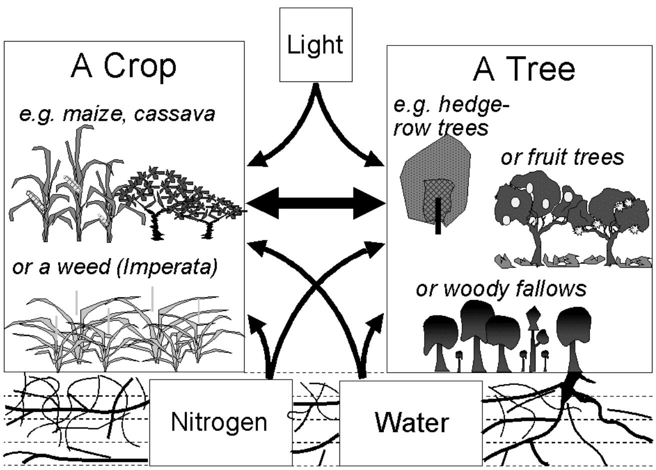


Figure 5. Components of the WaNuLCAS model

-- Example of WaNuLCAS simulation as a tool for diagnosis

Photo 18: Hedgerows of *Peltophorum* in fields of maize.
(*photo: Meine van Noordwijk*)

The WaNuLCAS model can predict some of the biophysical benefits and consequences that are commonly attributed to agroforestry systems. In the following examples, the simulations presented were made to evaluate the effect of tree-crop interaction in hedgerow intercropping systems (Photo 18) on increased productivity, improved soil fertility, nutrient cycling and water balance.

The WaNuLCAS model version 2.0 (van Noordwijk and Lusiana, 2000) was used to simulate different scenarios on a daily time step for 9 years for some of the described cropping systems (Table 4) established on an Ultisol at the Biological Management of Soil Fertility (BMSF) Project site (4^o 31' S, 104^{o}55' E), Kotabumi, Lampung, Indonesia. An annual total rainfall of 3102 mm (1 Nov 1997 – 31 Oct 1998) was used in the simulations.

Table 4. Scenario of cropping systems for WaNuLCAS simulations

Cropping systems		Explanation
1	*Maize-maize monoculture*	Without fertilizer
2	*Maize-maize monoculture*	With fertilizer 90 kg N ha^{-1} applications every planting
3	*Peltophorum*+maize-maize hedgerow intercropping	Without fertilizer
4	*Peltophorum*+maize-maize hedgerow intercropping	With fertilizer 90 kg N ha^{-1} applications every planting

Note: (+) multiple cropping; (-) followed by.

Predicted maize yield

The simulations indicated that maize yields would decrease over time in both the first and second cropping season of the year if no N fertilizer is used (Figure 6A and B, lower two lines). Hedgerow intercropping would slow down, but not stop this decline in the first crop of each year (Figure 6A), and have a positive impact on the second crop throughout (Figure 6B). An annual application rate of 90 kg of N per ha would be enough to maintain crop production (Figure 6A and B upper two lines), but in the absence of N limitation, the net effect of hedgerow intercropping would be slightly negative.

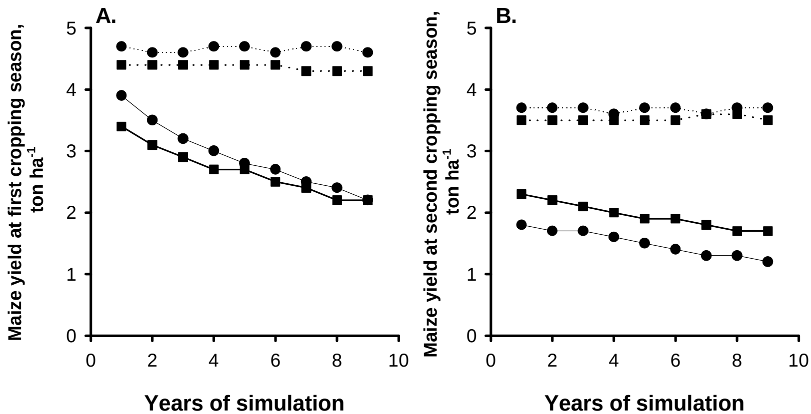


Figure 6. The effect of different cropping systems on maize yield of the first cropping season (A) and maize yield of second cropping season (B), where (●) is the monoculture system and (■) the *Peltophorum* hedgerow intercropping system; either without (_) or with (…) fertilizer application (90 kg N ha-1)

Predicted soil C

Photo 19. Continued biomass transfer is important to maintain soil organic matter content as tested in this experiment at the BMSF site in Lampung. (*photo: Kurniatun Hairiah*)

Continuous organic matter application can maintain soil organic matter, the more organic matter applied the 'cooler' the soil will be (Photo 19). The results of the simulations indicated that soil organic matter (soil C and N, Figure 7 A and B, respectively) declined over time. Hedgerow intercropping can slow the decline somewhat, especially in combination with N fertilizer use, but can not maintain the soil in its original, forest-like condition.

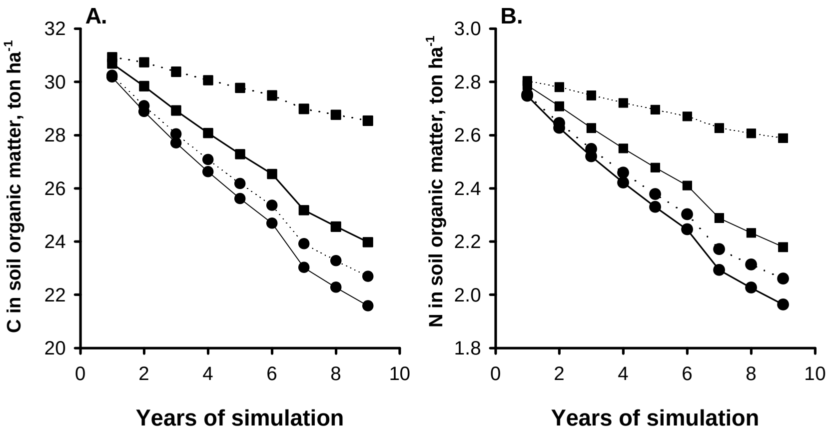
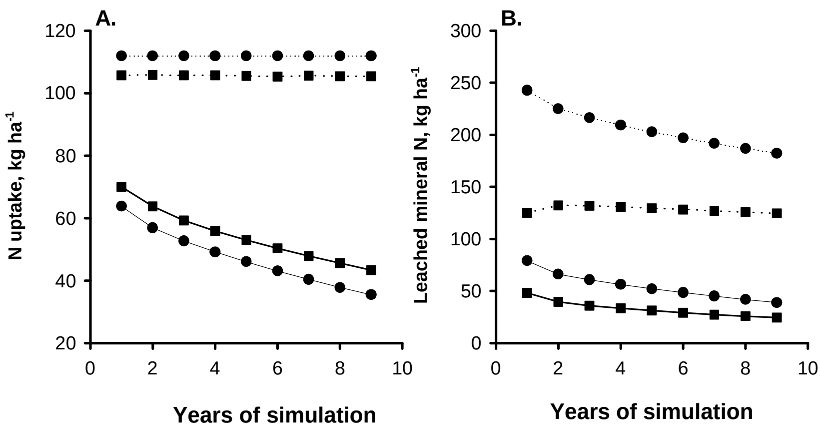


Figure 7. Trends of C-total in soil organic matter (A) and N-total in soil organic matter (B) in different cropping systems where (●) is the monoculture system and (■) the *Peltophorum* hedgerow intercropping system; without (_) and with (…) fertilizer (90 kg N ha^{-1}) applications.

Predicted N balance

The simulation suggested that maize without application of N fertiliser had a higher N uptake in hedgerow intercropping than maize in the monoculture system. When we apply N fertiliser, however, maize took up more N in monoculture than in hedgerow intercropping (Figure 8 A).

By far the largest losses of N by leaching occurred in the maize monoculture with fertilizer added (Figure 8 B). Hedgerow intercropping reduced the losses by about 40% of their value in the mono-culture, both with and without N fertilizer application. This is the ‘safety-net function’ discussed before.



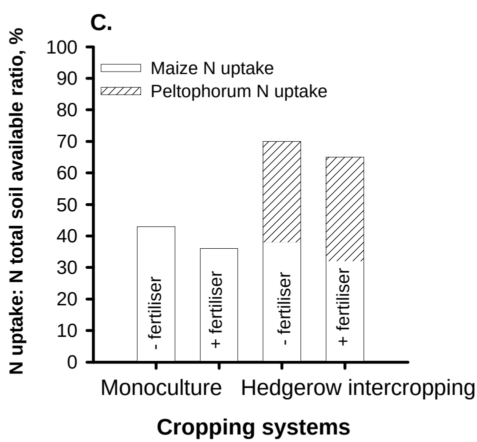


Figure 8. The effect of different cropping systems on maize N-uptake (A), on leached mineral N (B) and on safety net efficiency (N-uptake: available soil N, %) (C), where (●) is the monoculture system and (■) the Peltophorum hedgerow intercropping system; either without (_) or with (…) fertilizer (90 kg N ha-1) applications

If we compare the N uptake by the crop to the amount of mineral N that was available over the growing season (Figure 8 C), we see that the maize crop was able to take up 43% in the situation without fertilizer, and 36% of the much larger amount where fertilizer was added. In the hedgerow intercropping system, maize uptake was 38 and 32% of total N available, for situations without and with N fertilizer, respectively. The hedgerow trees took up an additional 33% both without or with N fertiliser use. Thus, total uptake was increased from 36 and 43% of available N in a monoculture with or without fertiliser use to a total of 65 or 70% in the hedgerow intercropping system, respectively. Losses by leaching were reduced by hedgerow intercropping from 30 to 57% in the absence of fertilizer, and from 35 to 64% where N fertilizer was used. These model predictions are generally in line with the field data (Box 1).

Predictions of the water balance: runoff and drainage

Two factors contribute significantly to nutrient losses in upland agriculture:

1. Runoff. Water that does not infiltrate to the soil can become surface run-off and lead to erosion and nutrient losses
2. Drainage. All water that infiltrates into the soil can cause leaching of plant nutrients

The simulations suggested that runoff in *Peltophorum* hedgerow intercropping was drastically lower than that in maize monoculture (Figure 9 A). Decreased runoff in hedgerow intercropping was due to increased water infiltration in hedgerow intercropping systems, and hence increased the water availability for maize and *Peltophorum* growth. Despite decreased runoff in the hedgerow intercropping system, water drainage was lower than that in maize monoculture (Figure 9 B) due to water use by the trees. Thus, water use by the trees reduces N leaching indirectly, and provides more time and opportunity for the root safety-net function by N uptake from deeper layers.

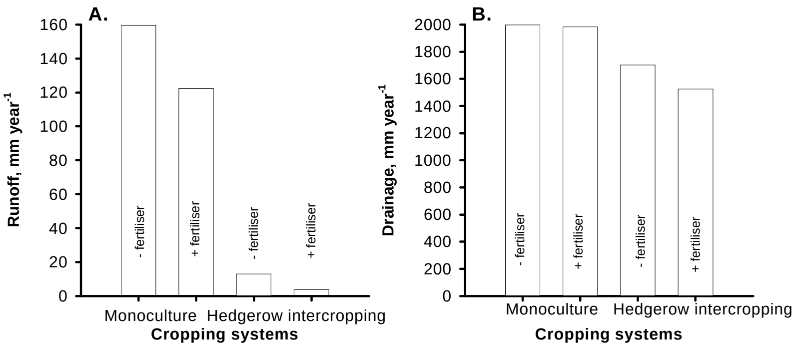


Figure 9. The effect of the fertilizer 90 kg N ha^{-1} applications on: (A) runoff and (B) soil drainage in maize monoculture and *Peltophorum* hedgerow intercropping systems.

Native soil C and fertilization in fallow - crop rotation

Farmers have a simple terminology for soil fertility by using the distinction '***hot***' versus '***cool***'. Soil scientists measure many properties but none of these matches exactly with this simple distinction. The closest we can come is the ratio of the organic matter content of the soil in its current condition, to that of a soil of the same texture and in the same climate under a long-term forest. On the basis of this simple ratio (C_{org}/C_{ref}), we can make model simulations of for example the response of a maize crop to N and P fertilizer, after a two year bush fallow (based on *Peltophorum* growth rate and properties). A C_{org}/C_{ref} ratio of 1 is a soil just derived from forest, called '***cool***' by farmers; values towards 0 are increasingly '***hot***', while values above 1 are '***cooler than cool'***….

The results of simulation show that predicted maize yield after a two-year fallow strongly responds to the soil '*coolness*' at the start of the fallow period. A two-year fallow can not do wonders on a soil that is already '*hot*' with a C_{org}/C_{ref} value less than 0.5 (Figure 10). Part of this effect can be explained by the fact that the trees themselves don't grow well. A target ratio of C_{org}/C_{ref} of about 0.8 is needed for attractive crop yields, in the absence of fertilizer. The yield of the third crop is more dependent on the initial fertility. When the soil is above this ratio the yield response to fertilizer will be low. In soils below this ratio, target crops are predicted to respond well to N fertilizer (the simulated fallow period has not added any N, only accumulated from soil pools).

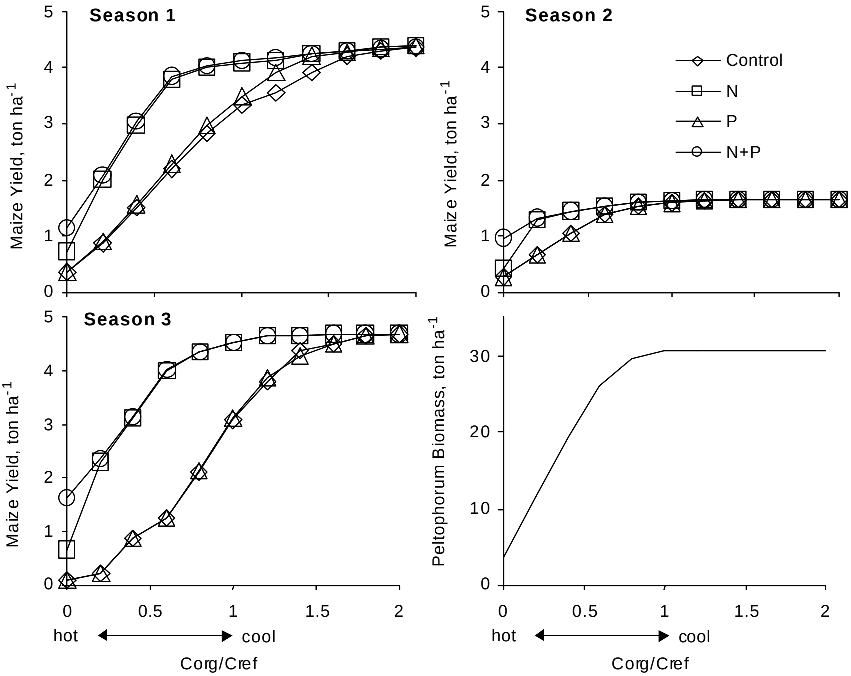


Figure 10. Predicted yield of maize over three seasons (season 1 and 3 in the wettest part of the year (December – March) for two subsequent years, season 2 in the drier April – June period, after two years of fallow dominated by the local tree *Peltophorum*, as a function of the initial organic matter content of the soil, with or without the use of N and/or P fertilizer. WaNuLCAS version 2.04 was used, on a soil with initial P-Bray values of 8,6,5,4 for soil layers 1,2,3,4 respectively, and otherwise the 'default' parameters.

The predicted response to P fertilizer is small, even at this relatively low initial P-Bray value. According to the model the organic matter supplies P to the crop as well as N, but N tends to be the first limitation. Yields in the second season are lower than those in the first and third because of water stress, and using fertilizer in this season will not help to improve crop yields, except where C_{org}/C_{ref} is less than 0.5 (but even so, it will probably not pay to do so at the low yield level).

Overall this example shows that we can translate the '*coolness*' property of the soil to the model and make sensible predictions of the responses to soil organic matter, the use of fertilizer and the difference between seasons and years.

-- Summarizing Tree–soil–crop interactions

When we combine all these aspects, we get the following picture of how a hedgerow intercropping system with *Peltophorum* could affect maize yield (Table 5).

Table 5. The effects of tree-crop interactions in *Peltophorum* hedgerow intercropping (HI) compared to maize monoculture.

Effects	**Indicators**	**The evaluation of Peltophorum HI*)**	
		Without N fertilizer	With N fertilizer
Increased productivity	Crop yield at first cropping season	0	-
	Crop yield at second cropping season	+	-
Improved soil fertility	Soil organic matter	+++	+++
Nutrient cycling	N uptake	+	-
	Leached mineral N	+	+++
	Safety net efficiency	++	++
Water balance	Runoff	+++	+++
	Drainage	+	+

*) Slightly positive (+), positive (++), very positive (+++), and slightly negative (-)

With the model we can explore how these results depend on the specific properties of the tree. *Peltophorum* does not have the ability to biologically fix nitrogen from the atmosphere. This explains the dependence on N fertilizer of the hedgerow intercropping system. But is it possible to use the 'safety-net efficiency' in a system where N fixing legumes create a surplus of N? What would happen if we mix two types of trees, one N-fixing and one non N-fixing? In the experiments at BMSF we tried the combination of *Gliricidia* and *Peltophorum*, but *Gliricidia* has superficial roots and is very competitive.

In the near future we hope that the model can be used by agricultural extensionists with the help of researchers to answer such questions, and to do a large number of 'mental experiments' that can help the farmers in learning faster and wasting less time on systems where the negative interactions will dominate over the positive ones.

-- How management of aboveground canopy influences roots

We have seen that tree-soil-crop interactions depend on the specific growth and form of the tree, aboveground as well as belowground. Thus there is an interest in understanding the degree to which these aspects can be influenced by management. We will consider two influences on tree root development here:

a) Does it matter for the root system at what height trees are pruned?

b) Does the planting technique matter for the root development of a tree?

These following examples are derived from trees used for hedgerow intercropping (Photo 20), but the principles will apply in other systems as well.

Photo 20. Pruning of hedgerow trees: leaves and small branches are returned to the soil, bigger branches are removed from the plot for firewood. (*photo: Kurniatun Hairiah*)

-- Pruning height

If we want tree roots to act as a nutrient safety-net, and not to compete with shallow-rooted food crops for water and nutrients, the tree roots should spread laterally, but below the crop root zone. An experiment conducted at the BMSF site showed that pruning trees closer to the ground can delay the shading effect on the crops, but it increases the number of tree roots in the topsoil rather than in the subsoil (Figure 11 and Photo 21). Shoot pruning leads to a temporary stop in root growth but if there are enough resources in the stem the root tips may survive and continue to grow later. If we prune close to the ground, many root tips die and the tree makes a new flush of roots starting from the stem-base, but mainly exploiting the topsoil. It is probably best to wait with the first pruning until the tree has a well-established deep root system. These results mean that if we really want an effective safety-net effect to assist in reducing nutrient losses, we may have to tolerate some negative impacts of shading. The best compromise may be to space the trees further apart, and manage them less intensively.

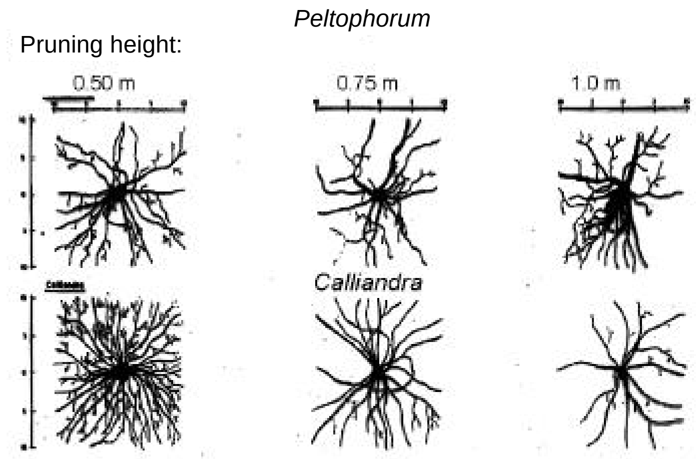


Figure 11. Views from above of the root distributions of old *Peltophorum* and *Calliandra* 6 months after pruning at various pruning heights (Hairiah *et al.*, 1992).

Photo 21. Root distribution of *Peltophorum* 6 months after being pruned at 50cm (left) or 75cm height (right). (*photo: Kurniatun Hairiah*)

--Planting technique

It is often believed that a tree that grows from seed in its final location, without any transplanting or nursery stage, will develop a deeper tap root than trees that are transplanted, or derived from cuttings, with their 'adventitious' roots. We did an experiment at the BMSF station to test this effect for *Peltophorum* and *Gliricidia*. *Peltophorum* was planted using (a) direct planting from seed, and (b) transferring seedlings from outside the plot. For *Gliricidia* we used (a) direct planting from seed, and (b) stem cuttings of 50 cm length. We measured above and belowground tree development in the first two years.

In the first evaluation (15 months after planting) we found that direct planting from seed produced a higher total root length than using seedlings or stem cuttings (Figure 12). Six months later, differences in root development between the two planting techniques had disappeared. Direct planting using seed is actually cheaper and does not need a lot of labour. However, trees grow slowly at the early stage, and therefore requires extra labour to control weeds. If supplies of stem cuttings are easily obtained, this planting technique has the advantage, because the tree can grow rapidly. The two techniques apparently have advantages as well as disadvantages.

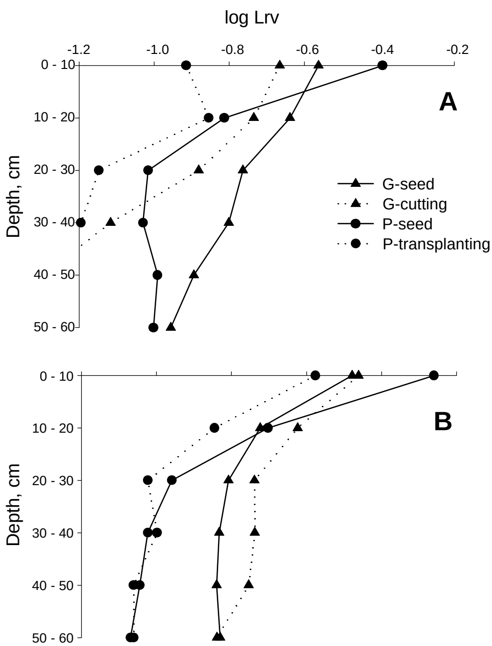


Figure 12. The effect of different planting techniques on total root length density (Lrv) in various soil depths at 3 sampling times (15, 18 and 21 months after planting).

Try It Yourself

The above explanation about tree-crop interactions may not lead to simple recipes of the type 'do this' and 'don't do that'. Much depends on local circumstances and preferences. ***There is no single agricultural system which is ideal!*** However, if farmers understand tree – soil – crop interactions, they can develop and improve their own management system on their own land. We can help with some tools: is the soil 'hot' or 'cool'? Are the tree roots superficial or deep? Can you afford to wait for trees to become productive, or do you need food crops for short term yields? Do you have enough land to sit back and let nature play its role, creating complex agroforests on your land, or do you want to manage your land more intensively, spending labour and money for inputs and hoping that it will work out? Agricultural extension cannot answer these questions for the farmer – but at least we can raise the questions…

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