Chapter 4
Examples of model applications

We first explore a simulation based on the 'default' parameters of version 3.0 and see how crops, trees and weeds interact and compete for N, P, water and light on soil rich in organic matter but with limited rooting depth due to subsoil acidity.

After that, five examples of model applications (made with version 3.0) are presented, to test the objective that the model can be applied to a wide range of agroforestry research questions.

Results are not compared to specific data sets and no parameter fitting has occurred. Examples are presented for simulation runs of a simple soil-crop system at different N fertilizer regimes, hedgerow intercropping systems at different hedgerow spacing and pruning regime, a test of the safety net function of deep tree roots, lateral interactions in crop-fallow mosaics and a first exploration for parkland systems with a circular geometry across a rainfall gradient and some more examples of WaNuLCAS application on the agroforestry research.

In each example, a list of input parameter changes is provided. These changes are relative to default values. If you have made recent changes in WaNuLCAS.stm and would like to return to default values for a group of parameters, click on undo button (U) at the top of list input device. If you want to reset all parameters to their default values, you can use a "Return to DEFAULT value" button in the "Input" section.

4.1 Simulation based on default parameter settings

For a start, the default parameter settings can be used to become familiar with the various types of model output that can be obtained. The default settings simulate an alley cropping system of maize and Peltophorum dasyrrachis. Figure 4.1 gives the biomass production results for a 'default' run of 2 years duration in which the trees are always pruned before planting a new crop. In the first cropping period there is little difference in crop growth between the three zones. In the first cropping season of year two, crop growth starts to differ significantly between zones and the crop in zone 2 (close to the hedgerow) produces less biomass compared to zones 3 and 4, as it faces more competition in terms of water, nutrient and light. During fallow period the hedgerow trees start develop more biomass until the next cropping season when the hedgerows are pruned; the woody part of the hedgerows is maintained, so overall aboveground tree biomass can gradually reach a higher level.

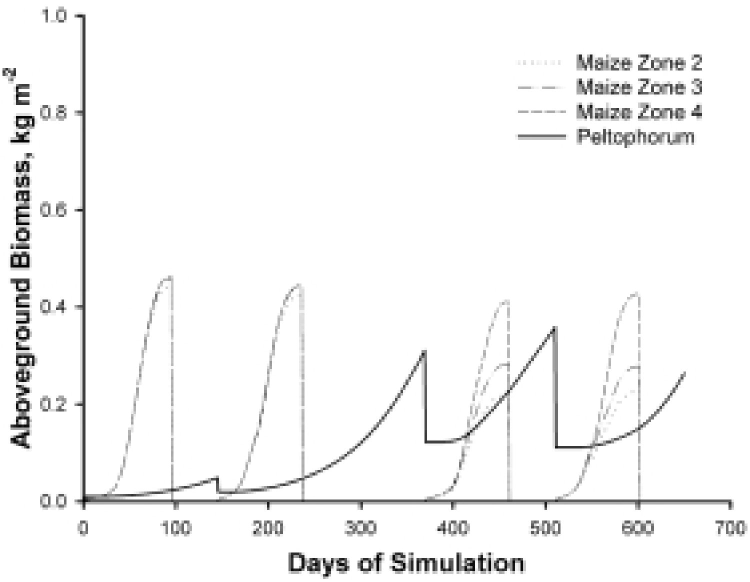


Figure 4.1 Biomass development of crop and tree for a WaNuLCAS 3.0 simulation using 'default' parameter settings

If you click on 'To View Water Input Output Summary' you will see results of the water balance. The only inputs of water were due to rainfall directly on the simulated area, as the default slope of 0% stops any Run-On or Lateral Inflow (but not the option of Run-Off). Out of a cumulative rainfall of 5812 mm (i.e. 2606 mm year^{-1}), 79 mm was used to recharge the soil (which was initialised below field capacity), 3723 mm drained from the soil profile, 174 mm became surface run-off, 636 mm evaporated from the soil surface, 146 mm evaporated from interception by crop and tree canopy, 731 mm was transpired by the crop and 324 mm by the tree. The BW_NetBal result of 4.5 10^{-13} indicates that the error in accounting for all inputs and outputs of water is negligible.

The N balance shows that there has been a considerable net mineralization of N during the simulation, with the SOM_N pools decreasing from 247 to 227 g m^{-2}. Neither crop nor tree fixed atmospheric N_2 and no N fertilizer was applied. The stock of mineral N has increased from 1.1 to 1.65 g m^{-2}, while 9.5 g m^{-2} was lost through leaching and 7.6 g m^{-2} was exported with crop harvest products. At the end of the run N the tree biomass was 2.2 g m^{-2} and the error term of the N balance was -5.68 10^{-14}.

In the P balance we again see that mineralization of organic P has been the major supply of P to the crop and tree, with the organic P stock decreasing from 57 to 55 g m^{-2}. In contrast to N, however, leaching losses have been very small (0.14 g m^{-2}). The error term of -1.8 10^{-13} again indicates that there are no problems of consistency.

The 'Filter Function' output sector indicates that overall the agroforestry system has been quite effective in capturing the N and P released from the soil organic matter before it leached out of the profile, with an overall filter efficiency of 67 and 98% for N and P, respectively. A substantial part of this overall filter function was located in the 'Edge': filter function horizontally was 17 and 73% for N and P, respectively; filter function vertically was 7 and 2% for N and P, respectively. The local filter efficiency in layer 3 (relative to leaching and lateral flow losses from each cell) clearly decreased from zone 2 to zone 4, with decreasing root length density of the tree. The overall filter functions are higher for P than they are for N as the lower mobility of P (relative to N) retards the leaching and increases the P residence time, giving more opportunity for uptake; this effect apparently exceeds the impacts on uptake of a larger diffusive resistance.

The C balance shows again the decrease in soil C during the simulation (2679 to 2438 g m^{-2} or 27 to 24 Mg ha^{-1}), while total photosynthesis of the tree is more than half of that by the crop (319 and 536 g m^{-2}, respectively), most of which was lost in respiration. At the end of the two years simulation, 335 g m^{-2} has been exported from the field in crop products, while the current tree biomass is 111 g m^{-2}. The error term of the C balance is negligibly small at 0, while the 'time-averaged C stock' is 2641 g m^{-2} (or 26 Mg ha^{-1}).

The 'Yields' sheet specifies the agronomic yields obtained from the system as a whole. Only the maize crops ('Type 2') are counted, as the trees did not (yet) produce any directly usable products, current tree biomass harvested comes from tree biomass pruned (8 Mg ha^{-1}). The maize grain yield of 0.94 kg m^{-2} or 9.4 Mg ha^{-1} (3.3, 3.1, 2.2 and 2.2 Mg ha^{-1} per crop, respectively) is quite good. During the simulation N, P and water limited crop growth 37, 64 and 0 % of days in the cropping period, and tree growth for 34, 13, and 0 % of the year.

The 'light' output shows crop growth limitation by light capture. The value 0.99 means the growth of the crop was hardly limited by light.

The 'soil balance output' gives result for the amount of soil loss and current topsoil thickness. As the default value for slope 0%, topsoil thickness after two years simulation is the same to the initial value means no soil was lost during the simulation.

4.2 The use of the main switches and changes in crop or tree type

A number of ways exist to further explore the backgrounds of these results and the way limitations by water, N, P and light interact. One method is to inspect the graphs of current limitations in each zone, as provided in the 'Output' section of the model. A second method is to use the main switches on the 'Output' level and try the various combinations of 'no trees', 'no water, N or P' limitations and 'presence of weeds' for the default setting of all other parameters. Figure 4.2 A-K show the tree and crop biomass results for such runs.

Figure 4.2 A-C shows the crop biomass as a result of changing tree species and absence of the tree. The presence of the tree (comparing Fig 4.2.A-B and C) affects crop growth in zones closer to the tree. Using Peltophorum (comparing Fig 4.2.A and C) crop growth starts to differ between zones at year 2. Changing the tree type from Peltophorum to Gliricidia in the Excel sheet 'Tree parameters' (comparing Fig. 4.2.A and B), the impact of tree on crop growth starts earlier, that is on the second crop season of the first year. The decrease of total tree biomass during a cropping period is due to pruning and use of internal reserves in the tree. For Gliricidia (Fig. 4.2.B), the total tree biomass decreases during fallow period (no crop). This is due to litter fall caused by drought, as Gliricidia is more sensitive to drought than Peltophorum.

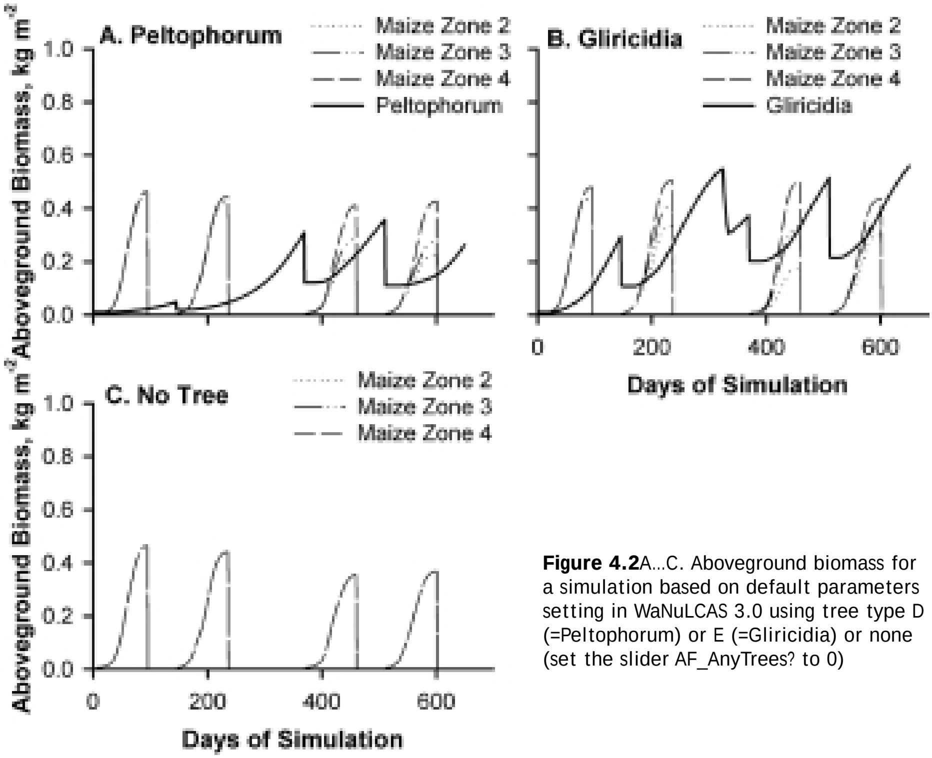


Figure 4.2A...C. Aboveground biomass for a simulation based on default parameters setting in WaNuLCAS 3.0 using tree type D (=Peltophorum) or E (=Gliricidia) or none (set the slider AF_AnyTrees? to 0)

Figure 4.2 D…G shows the tree and crop growth without water, N or P limitations. Figure 4.2 D…G indicate that removing the impacts of P limitation has by far the strong impact on overall crop growth. In its normal condition, crop growth during the second year is severely limited by P.

Figure 4.2 H...K show the impact of tree and weed presence in the systems. Current default settings are without weed and with tree. 'Weed growth' can be simulated by specifying the slider AF_SimulateWeeds? in Run and Output section to 1. To set with or without a tree situation, specify the slider AF_SimulateTrees? in Run and Output section to 1 or 0.

The pattern starts to become fairly complex, as the C_Biom output in zone 2...4 alternately refers to a crop and weed, while the weed growth in zone 1 is out of phase with the weed growth in zone 2...4. Weeds only grow during the fallow periods (no crop) in zone 2…4. In Figure 4.2.I, a tree is added to this pattern; note that the tree is not pruned when weeds occupy

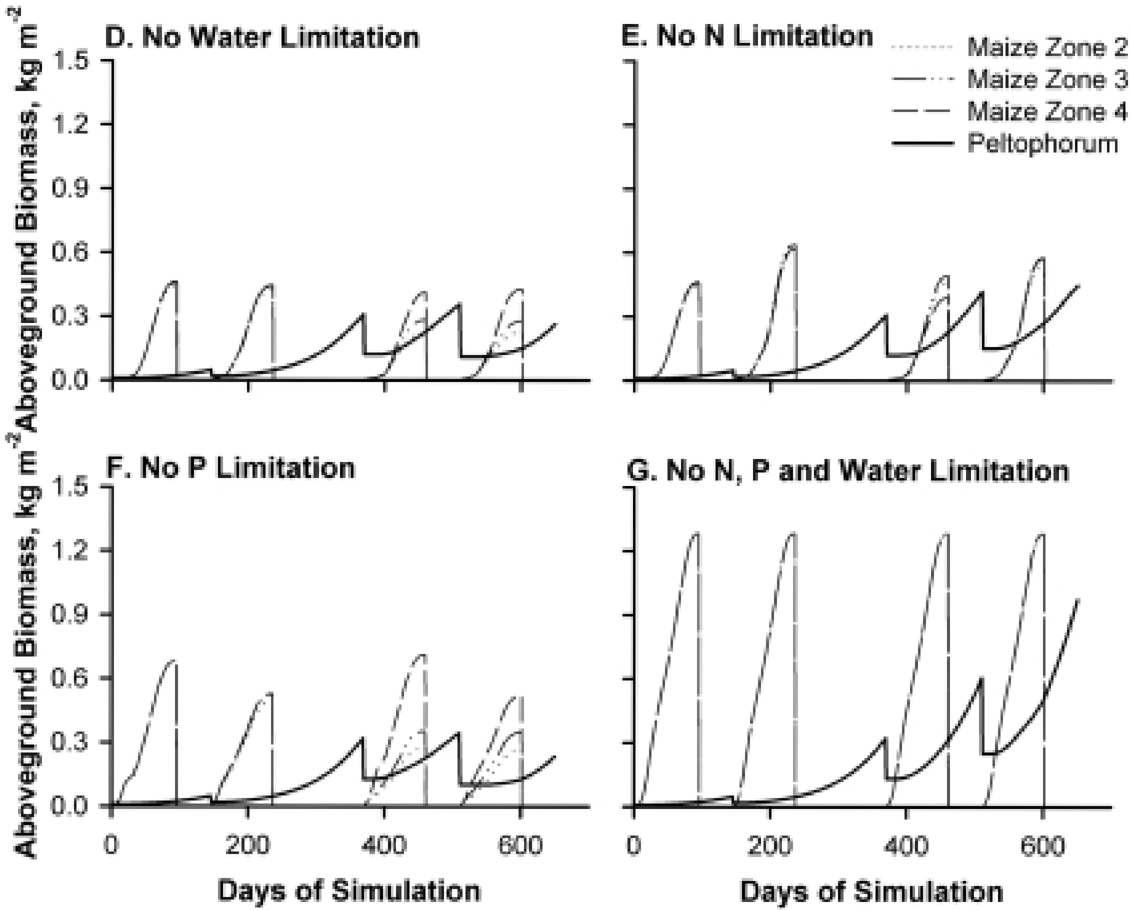


Figure 4.2.D...G. Aboveground biomass for a simulation based on default parameters setting in WaNuLCAS 3.0 as impact of N, P and water limitation

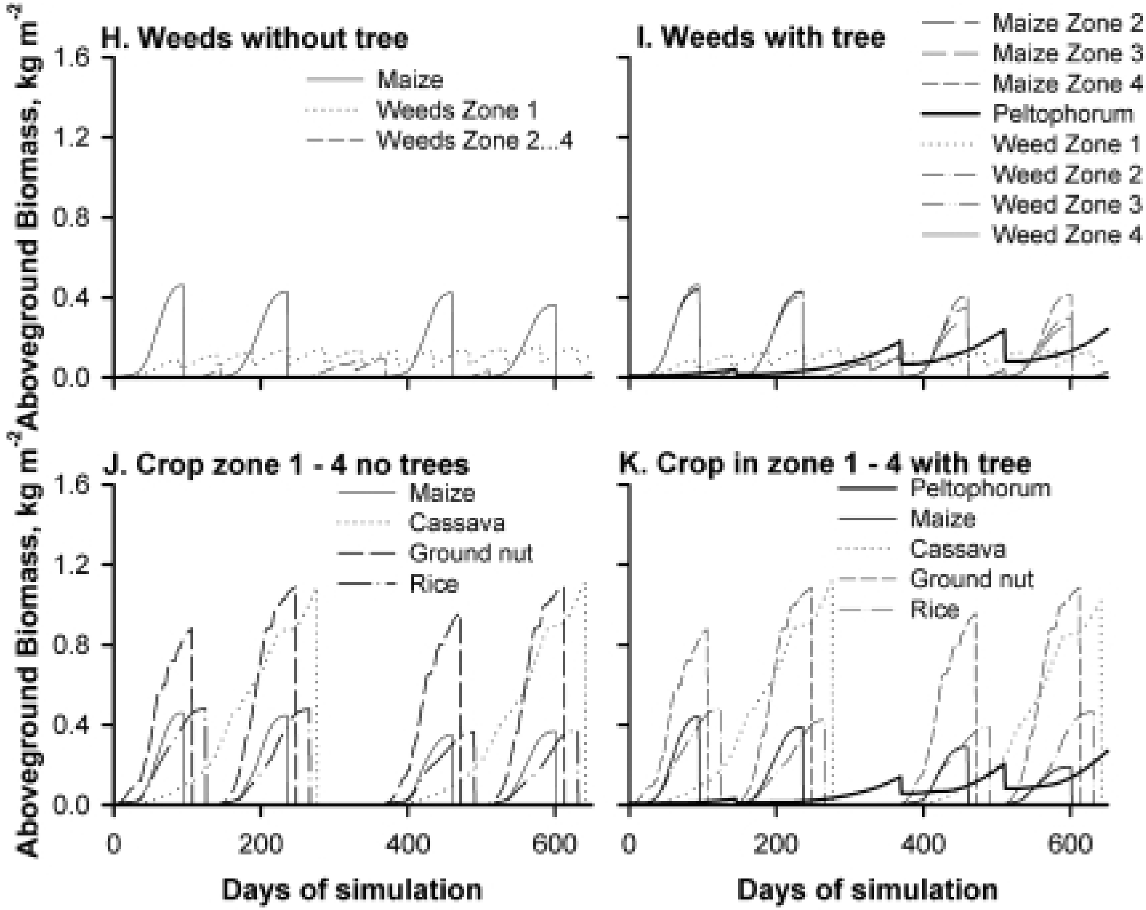


Figure 4.2.H...K. Aboveground biomass for the simple modification (less than 5 mouse clicks) of the default parameter setting in WaNuLCAS 3.0; for explanation see text

zone 2…4; the tree has some impact on weeds in zone 2, but apparently is not very effective in reducing weed growth.

Figure 4.2.J, compare the results for four crop types, each grown in separate zones and each following their own phenological cycle. To obtain this run, return to 'default' settings, set the slider AF_AnyTrees? in 'Run and Output' section to 0 and change the crop types on the 'crop management' sheet in the excel file (Maize in zone 1, Cassava in zone 2, Ground nut in zone 3 and Rice in zone 4). Note that when a tree is added to the systems (set the slider AF_AnyTrees? back to 1), as shown in Fig. 4.2.K, it will be pruned every time prior to planting crop. The presence of the tree significantly affects the biomass of maize that grows closer to the tree.

4.3 Crop-only controls with N and P fertilizer

We will normally want to compare agroforestry options with a crop only and / or tree only run for the same soil and climate. As an example we use data for maize growth in Lampung (Indonesia) as inspiration for the default case.

On flat land, in the absence of a tree, there is no interaction between the crop zones. So, we can simultaneously make runs for four N fertilizer regimes (0 in zone 1, 60 in zone 2, 90 in zone 3 and 120 in zone 4, kg N ha^{-1}), by specifying Ca_FertApply?[N] as 1. The amount of N fertilizer equals to 0, 6, 9, and 12 g m^{-2} that applied twice, half at planting time and half at a month after planting time. For simplicity, we used the same amounts for P fertilizer by specifying Ca_FertApply?[P] as 1. It is applied once at planting time. Fig. 4.3 the simulation beside run at the different of fertilizer application also knows the impact of reducing 50% of soil organic matter content by reducing Mn_InitAct, Mn_InitPass and Mn_InitSlw 50% (see table 4.1 for details of changes from the default parameter setting).

The simulation (Fig. 4.3) was extended to two years, with four consecutive crops of maize. For unfertilised plots with default soil organic matter, crop biomass development started with a good initial crop biomass (with a total biomass of over nearly 0.5 kg m^{-2} (= 5 Mg ha^{-1}), but the biomass declined to 20% of the first year's value in year 2. By reducing 50% of soil organic matter, crop biomass declined to 30% of default value of soil organic matter.

By applying different amount of fertilizer for N and P, the results show that the higher fertilizer, the higher crop biomass. Reducing 50% of soil organic matters does not show significant different on the crop biomass when N and P fertilizer was applied together. Response of the reducing soil organic matter on crop biomass is obtained when only P fertilizer was applied.

Table 4.1 Input parameter modifications from default to generate example 4.3.

Parameter		Input Section (Link Location in Excel)
INPUT	New Value	
AF_AnyTrees?	0	Run and Output Section
Ca_FertOrExtOrgAppYear	0, 0, 0, 1, 1, 1, 1, 1, 1, 2, 2,2	(Crop management/Fertilizer and organic input schedule)
Ca_FertOrExtOrgAppDoY	305, 306, 335, 81, 82, 111, 305, 306, 335, 81, 82, 111	(Crop management/Fertilizer and organic input schedule)
Ca_FertApply?[N] Ca_FertApply?[P]	1, 0, 1, 1, 0, 1, 1, 0, 1, 1, 0, 1 0, 1, 0, 0, 1, 0, 0, 1, 0, 0, 1	(Crop management/Fertilizer and organic input schedule)
Ca_FertOrExtOrgAmount [Zn1…4] N1[Zn1,2,3,4] N2[Zn1,2,3,4]	 0,30,45,60 0,30,45,60	(Crop management/Fertilizer and organic input schedule)
Ca_FertOrExtOrgAmount [Zn1…4] P[Zn2,3,4]	 0,60,90,120	(Crop management/Fertilizer and organic input schedule)
Mn2_InitAct[Zn1…4]	0.0455	Soil Organic Matter/Initial C & N in SOM Pool
Mn2_InitSlw[Zn1…4]	0.505	Soil Organic Matter/Initial C & N in SOM Pool
Mn2_InitPass[Zn1…4]	0.364	Soil Organic Matter/Initial C & N in SOM Pool

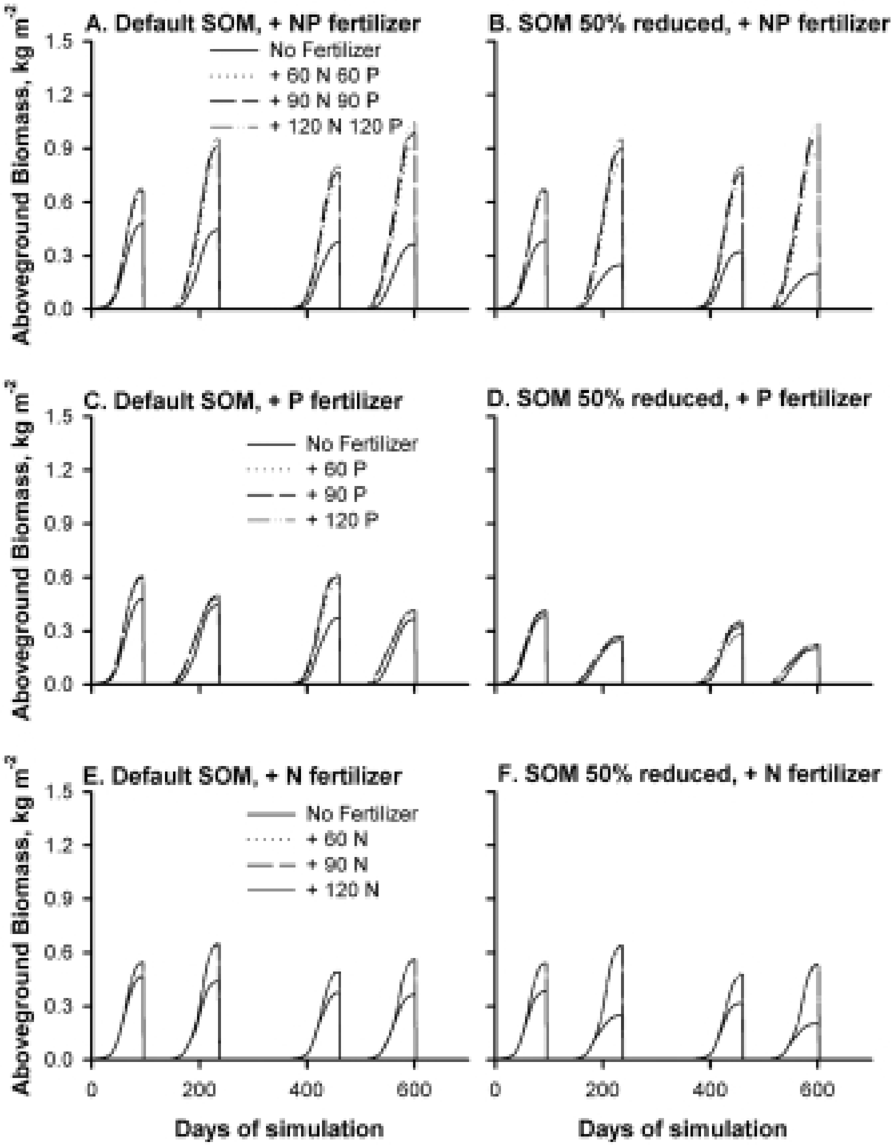


Figure 4.3 A...F. Simulated crop development (total aboveground biomass) for maize with a Lampung climate and default parameters setting (for changes in parameter settings from the default values, see Table 4.1), with or without N fertilizer (at 60, 90 or 120 kg N ha^{-1} $crop^{-1}$, with split application (50% at planting, 50% at 30 days later). We also used the same amounts for P fertilizer; it is applied once at planting time. The simulation also knows the impact of reducing 50% of soil organic matter content.

4.4 Hedgerow intercropping: pruning regime and hedgerow spacing

Based on different tree characteristics ('P' and 'G' in Figure. 4.4), the model predicts different pruning frequencies to be applied (one per crop for P and two to three times per crop for G) by making modifications from the default settings as indicated in Table 4.2. The 'P trees' have some characteristics in common with Peltophorum as we know that in Lampung experiments while the 'G-tree' simulates Gliricidia (Van Noordwijk, 1996a).

The WaNuLCAS model can also predict crop yields in different strips (zones) within the alleys in a hedgerow intercropping system, by making modifications from the default settings as indicated in Table 4.3. The simulations presented here were made with version 3.0 as a first approximation of long-term hedgerow intercropping experiments in Lampung (Indonesia); details of the experiments that form the inspiration for these simulations can be found in Van Noordwijk *et al*. (1998a).

Compared to the maize series of Fig. 4.1 and 4.2 which we include as 'control', the P trees can partly alleviate the yield decline over time, while the G trees the second crop in each year produces more biomass than the first crop. Averaged over four crops and expressed on a whole-field basis, predicted crop yields for the P hedgerow intercropping system are similar to this control crop while for the G hedgerow intercropping system are slightly higher than this control crop. Hedgerow intercropping will clearly give increased crop growth in zone 4, where the positive effects of mulch are felt, without much shading.

The overall trend in crop yields is negative for P trees and less so for G trees, as the P system is gradually depleting its N stocks, in the absence of atmospheric N_2 fixation in P trees or maize. In the long term field

Table 4.2 Input parameter modifications to generate example 4.4

Parameter		Input / Output Section location
INPUT	New Value	
T_PrunLimit	0.1	Management / Pruning Events

experiments in Lampung crop yields for the control indeed declined rapidly, but no such yield decline was recorded for the treatments resembling P trees.

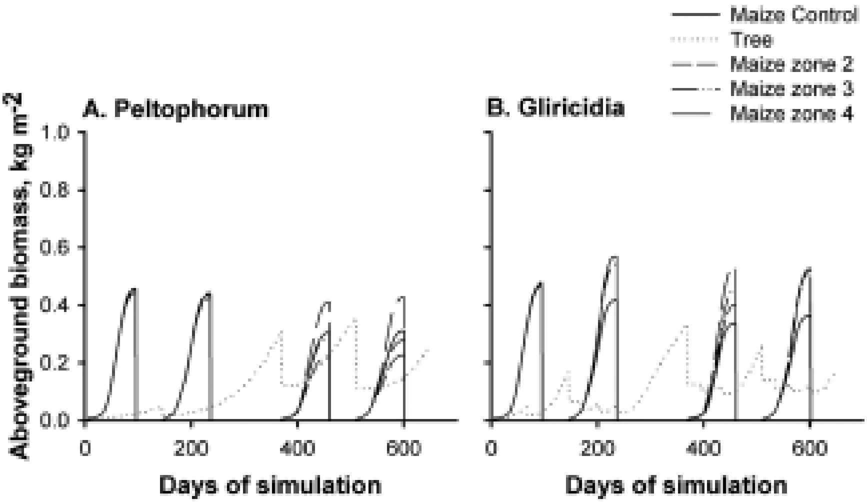


Figure 4.4 Model predictions with WaNuLCAS 3.0 of development of hedgerow tree canopy and crop biomass (on a whole field basis) over four cropping seasons in two years, for three crop zones (2, 3 and 4) within the alleys (the P and G trees approximate Peltophorum and Gliricidia, respectively, as used in experiments in Lampung (Indonesia); van Noordwijk *et al*., 1998a); zones 2, 3 and 4 are 1 m wide each; soil type, rainfall pattern and potential maize production inputs were derived form the Lampung site

Table 4.3 Input parameter modifications to generate example 4.5

Parameter		Input / Output Section location
INPUT	New Value	
Same settings as above with different AF_ZoneTot		Agroforestry zone
AF_ZoneTot	4, 8, 16, 32	
AF_Zone[Zn1]	0.5, 0.5, 0.5, 0.5	
AF_Zone[Zn2]	1, 1, 1, 1	
AF_Zone[Zn3]	1, 1, 1, 1	
AF_Zone[Zn4]	1.5, 5.5, 13.5, 29.5	
T_PrunLimit	0.1, 0.3	Management/Pruning Events

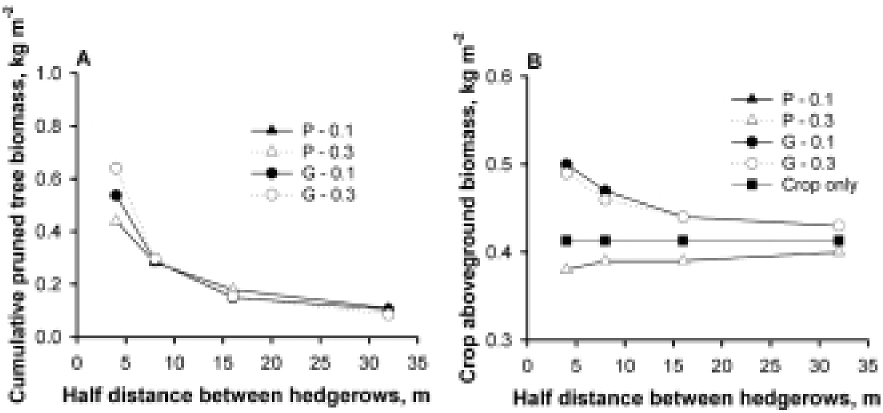


Figure 4.5 Predicted effect on cumulative pruned tree biomass (A) average crop biomass of four cropping seasons (B) if the distance between two hedgerows is gradually increased; results are given for P and G trees (compare Fig. 4.2 and two values of the 'prune limit', i.e. the hedgerow canopy biomass at which hedgerows are pruned back (For details see Table 4.3); and control refers to a whole field planted with crops

The G parameterisation (wider canopy shape, lower LAI within the canopy, shallower roots, N fixation) leads to crop yields that are substantially above the control yields due to biomass pruned from Gliricidia higher than Peltophorum. From the third crop onwards, however yields in zone 3 as well as 2 will be higher than those in the control. In the longer run hedgerow intercropping with G trees is predicted to lead to substantial gains over the pure crop control.

If the distance between hedgerows is gradually increased (Fig. 4.5), the various positive and negative effects on crop yield result in a rather complex overall response. The cumulative pruned biomass clearly decreases with increased hedgerow spacing, but differs remarkably little between the two values of the prune limit: the higher frequency of pruning at a low prune limit compensates for the smaller biomass per pruning event. Crop biomass with the G tree tends to be decrease with increasing of the distance between hedgerows but still above the control value while with the P tree crop biomass slightly increase although below the control value.

The P trees with different prune limit does not give significant different on the crop biomass, while the G tree with high prune limit (G = 0.3) crop biomass lower than G tree with lower prune limit (G = 0.1).

In contrast to Fig. 4.2, the results of Fig. 4.5 can not be compared with any existing experiments we know of, as hedgerow spacing has seldom been systematically evaluated in hedgerow intercropping experiments. The pattern predicted here is more complex at wider hedgerow spacing than the simple 'shade and mulch' model of Van Noordwijk (1996b), which did not consider spatially zone effects (which matter especially at wider spacing).

4.5 Tree fallow - crop rotations

The WaNuLCAS model can also be parameterised for simulating crop yields on small farms where part of the plot is currently under a tree fallow (such as the Sesbania fallows currently tested in Southern Africa), and other parts are cropped. The crop-fallow mosaic will not be drastically different from a hedgerow-intercropping situation: the spacing between hedgerows is wider, broader zones of tree growth replace hedgerows and the pruning regime is modified, but otherwise the processes of tree-soil-crop interactions are the same.

The simulations presented here were made with version 3.0 based on default setting with not applying fertilizer. Parameters modification needed to simulate the system are shown in Table 4.4. The simulation requires two runs in which output from the 1st run becomes input for the 2nd run. Notice also that output values from the tree zone should become the input values in crop zone and vice versa. The soil nutrient content of the tree zone can be directly used as input for crop zones while we need to start the tree zone with the weighted average of output from crop zones. Here is an example of how to do that for initial N in 1st soil layer.

For the tree zone:

N_Init1[Zn1] = (AF_Zone[Zn2]*N_Soil1[Zn2]+AF_Zone[Zn3]*N_Soil1[Zn3]+ AF_Zone[Zn4]*N_Soil1[Zn4]) / (AF_Zone[Zn2]+AF_Zone[Zn3]+AF_Zone[Zn4])

For the crop zone:

N_Init1[Zn2] = N_Init1[Zn3] = N_Init1[Zn4] = N_Soil1[Zn1]

The soil organic matter pools increased is size during a fallow period (in the model mainly by litter fall, which is supposed to be mixed through the upper soil layer by abundant faunal activity) and depleted during cropping. The model predicts that there will be substantial 'border effects' of the fallow on neighbouring crop land, not only caused by shading (zone 2) but also by root competition (zone 3).

Table 4.4 Input parameter modifications from default to generate example 4.6 and output parameters to retain.

Parameter for 1st run			Location on WaNuLCAS Input/Output Section
INPUT	**New Value**		
AF_Zone[Zn1] AF_Zone[Zn2] AF_Zone[Zn3]	10 2 3		Agroforestry Zone
AF_ZoneTot	20		Agroforestry Zone
Ca_PlantYear[Zn2…4]	0, 1, 1, 2, 2, 3, 3, 4		Crop Management
Ca_PlantDOY[Zn2…4]	304,80,304,80,304,80,304,80		Crop Management
T_CanHMax	5		Tree Library/Canopy
T_CanWidthMax	12		Tree Library/Canopy
T_PrunPlant?	0		Management/Pruning Event
T_PrunYear	2		Tree Management
T_PrunDOY	300		Tree Management
T_PrunFracD	0.7		Tree Management
Ca_FertOrExtOrgAppYear	100		Crop Management
	Graph A	**Graph B**	
Rt_TLrvL1[Zn1…4]	4, 1.6, 0.64, 0	4, 4, 4, 0	Tree Library/Root
Rt_TLrvL2[Zn1…4]	1, 0.4, 0.16, 0	1, 1, 1, 0	Tree Library/Root
Rt_TLrvL3[Zn1…4]	0.5, 0.2, 0.08, 0	0.5, 0.5, 0.5, 0	Tree Library/Root
Rt_TLrvL4[Zn1…4]	0.1, 0.04, 0.016, 0	0.1, 0.1, 0.1, 0	Tree Library/Root
OUTPUT	**Remark**		
Mn_Act[Zone]	Use Values at the end of run as initial values for the 2nd run		
Mn_Slw[Zone]			
Mn_Pass[Zone]			
Mn_Struc[Zone]			
Mn_Metab[Zone]			
Mn2_Act[Zone]			
Mn2_Slw[Zone]			
Mn2_Pass[Zone]			
Mn2_Struc[Zone]			
Mn2_Metab[Zone]			
W_Thetai[Zone]/ W_FieldCapi[Zone]			
N_Soili[SlNut,Zone]			

Parameter for 2nd run		Location on WaNuLCAS Input/Output Section
INPUT	**New Value**	
Same setting as 1st run with additional below		
AF_Zone[Zn1] AF_Zone[Zn2] AF_Zone[Zn3]	5 3 2	Agroforestry Zone
AF_ZoneTot	20	Agroforestry Zone
Ca_PlantYear[Zn1…3]	0, 1, 1, 2, 2, 3, 3, 4	Crop Management
Ca_PlantDOY[Zn1…3]	304,80,304,80,304,80,304,80	Crop Management
Mn_Act[Zone]	Use Values resulted from 1st run. Make sure result from crop zones become input from tree zone and vice versa (see explanation in text)	
Mn_Slw[Zone]		
Mn_Pass[Zone]		
Mn_Struc[Zone]		
Mn_Metab[Zone]		
Mn2_Act[Zone]		
Mn2_Slw[Zone]		
Mn2_Pass[Zone]		
Mn2_Struc[Zone]		
Mn2_Metab[Zone]		
W_Theta*i*[Zone]/ W_FieldCap*i*[Zone]		
N_Soil*i*[SlNut,Zone]		
OUTPUT		
T_Biom		Table 1 page 1
C_Biom[Zn1…3]		

The WaNuLCAS model may offer the first opportunity to consider crop-fallow mosaics as a coherent system, in stead on only regarding the sequential effects on plots that are supposed to be spatially isolated. The models may stimulate a renewed research attention on border effects in crop-fallow experiments, as no published data exist on the topic. Substantial border effects of teak (Tectona) stands in Java (Indonesia) were described in the 1930's (publications of Coster, reviewed in Van Noordwijk *et al.*, 1996), and these were larger than what WaNuLCAS predicted for the parameters in Fig 4.6. Unfortunately, no tree root length densities are known for these (or similar) teak stands. Border effects in crop-fallow mosaics make that the overall effect will depend on the scale (absolute plot size) and not only on the crop: fallow ratio.

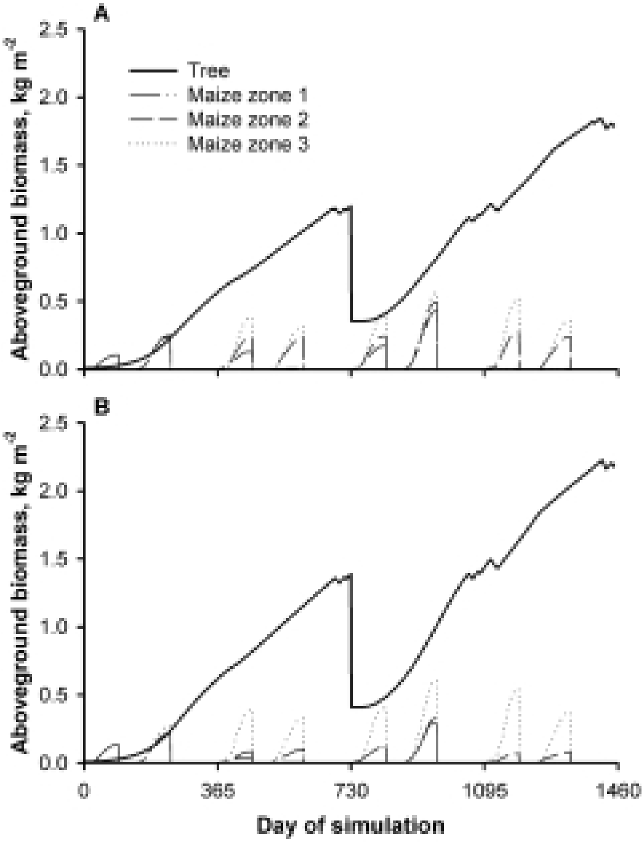


Figure 4.6. Predicted development of a tree fallow vegetation as well as the simultaneous yield of crops with increasing distance to this fallow plot, over two cycles of a two year fallow and 2 years of cropping (4 crops/ cycle); A. tree root length density decreases by a factor 0.6 from zone 1 to zone 2 and again from zone 2 to zone 3; no tree roots in zone 4; B. Tree root length density in zone 2 and 3 is equal to that in zone 1, but there are no tree roots in zone 4

4.6 Contour hedgerows on sloping land

Figure 4.7B gives initial results for a contour hedgerow system on sloping land, cumulated over four crops. The simulations presented here were made with version 1.1. Model comparisons were made to separate the terms of the general tree-soil-crop interaction equation (Chapter 1), but adding two effects of slope: 1. Topsoil can be redistributed from the upper to the lower part of the alley, forming a terrace, but exposing crops in the upper alley to subsoil with a lower organic matter content, 2. Water will be re-distributed by run-off in some zones and run-on in others. If we follow the lines in the figure from left to right, we see that the effect of not growing crops on the space reserved for hedgerows is negative, but that the uneven water infiltration can make up for the yield loss in the humid series (it reduces N leaching from the crop zone). Considering a regularly pruned hedgerow on the contour instead of a bare strip has a moderate positive effect on crop yields, but terrace formation has a negative effect on yields. For the sub-humid series all effects are weak, and no treatment combination can make up for the space lost to make the contour strip. The results per crop zone (Figure 4.7C and D) contain some surprises, as they show a range of patterns between crops: for some crops the middle of the alleys gives the highest yield, for others the lower alley, or even the upper alley. Although all types of patterns can be observed in real-world experiments, it is surprising that the balance of positive and negative interactions can, apparently, change so easily in the complexity of the WaNuLCAS model. Stride for prominence. Further model validation is necessary before any soil, climate, tree and crop specific model predictions should be seen as more than 'interesting hypotheses'.

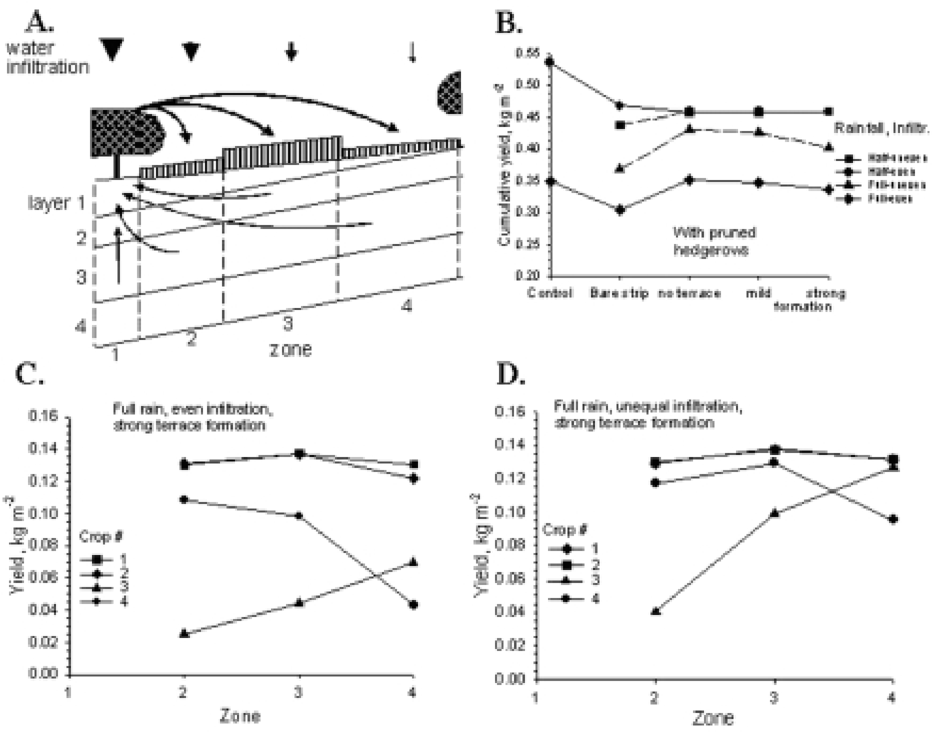


Figure 4.7. Calculations with the WaNuLCAS model (Van Noordwijk and Lusiana, 1999) of crop yield in a contour hedgerow system on sloping land; A. Model scheme for applications on sloping land; B. Cumulative yield over four crops (2 years) for a humid (3 000 mm/year) and sub-humid (1 500 mm/year) climate, with and without uneven infiltration of rainfall over the respective zones; C. and D. results per crop and zone

4.7 Tree-soil-crop interactions across a rainfall gradient

To further explore the sensitivity of the model a series of calculations was made for an agroforestry system with scattered trees and crops growing on all land except for a circle directly around each tree (Fig. 4.8).

For these runs the soil profile consisted of four layers (15, 15, 50 and 30 cm thick, respectively) and had a sandy texture (61% sand, 11% silt, 28% clay) and a bulk density of 1.3 Mg m^{-3} and thus had a rather low water holding capacity according to the pedotransfer function. Calculations were made for five climate zones, based on random daily rain events with a set monthly average and daily rainfall probability of about 20%. The five climates consisted of:

- annual average 240 mm (1 month of 30 mm, followed by 3 months of 60 mm and 1 month of 30 mm; in practice the average was 285 mm for the runs presented here),
- annual average 450 mm (1 month of 75, followed by 3 months of 100 and 1 month of 75 mm; in practice the average was 525 mm)
- annual average 1000 mm (1 month of 125, followed by 5 months of 150 and 1 month of 75 mm; in practice the average was 937 mm)
- annual average 1500 mm (10 months of 150 mm; in practice the average was 1645 mm)
- annual average 2400 mm (12 months of 200 mm; in practice the average was 2285 mm).

As the same starting value was used for the random generator, all runs for different agroforestry systems in a given climate were made with the same daily rainfall pattern. The simulation run was 2 years, and two crops were grown per year for the 1500 and 2400 mm rainfall zone. Simulations for pure crops (covering the whole field) were compared with those of trees only (unrestricted tree growth) or agroforestry systems where trees occupied the inner circle and crops the remainder of the land. The trees were pruned at sowing time for each crop, and a second time during the crop if their biomass exceeded a set value of 0.2 kg m^{-2} (averaged over the whole field). For comparison a set of simulations was included where the tree was pruned in the same way as in the agroforestry system, but where no crop was grown. Four variants were considered for the agroforestry system, indicated by 'narrow', 'medium', 'broad' and 'very broad' tree canopies with a crown diameter of 1, 2, 3 or 4 quarts of the diameter of the whole system. Note that all zoning is relative to tree size and no absolute distances have to be specified. Tree root length density was 2, 1.5, 0.6 and 0.2 cm 3 for the four depth layers directly under the tree, respectively, and 0.6, 0.36, 0 times that value in the three other zones, respectively; thus tree roots were confined to a circle of 3/4 the total diameter. The tree was able to derive 40% of its daily N demand by atmospheric nitrogen fixation and tree N could be transferred to the crop via litter fall and tree prunings, based on a gradual N mineralization. The crop was supposed to have a 98 day duration and a rather shallow root system, with a harvest index under non limiting conditions of 41%. No N fertilizer was used.

From the simulation results using WaNuLCAS version 1.1, we focus here on grain production (actual harvest index was between 36 and 41%), stem wood production for the tree (treating crop residues, litter fall, pruning and current tree canopy as intermediate components of the system). The simulation involved a gradual shift from water to nitrogen as the major factor limiting crop production. At high rainfall the total N the first crop in the pure crop control effectively exhausted supply in the soil and the three following crop yields were low. Under these conditions the agroforestry system could increase crop yield (by up to 8%), by supplying at least some N for the later crops, thus compensating for the area without a crop and competition effects on crop growth. The medium tree canopy shape (2/4) gave the highest crop yield of all agroforestry systems in the three wettest climates. For the simulations at 450 and 240 mm rainfall, crop yields were reduced in agroforestry by 11 and 35% respectively, as competition for water dominated over positive effects on N supply; at 450 mm the four agroforestry systems gave equal grain yields, while at the 240 mm run, the narrow tree morphology was best. In contrast to grain yield, wood production was always higher in the pure tree system than in the agroforestry system. The narrow tree morphology produced more wood, as it invested less resources in a leaf + fine branch canopy.

Total yield for the agroforestry system can be calculated if the value of wood can be expressed relative to that of grain. In Fig. 4.8 a 1:4 ratio is used. In the driest simulations there is agroforestry system will reduce total yield, while the curve for the 450 mm zone is nearly flat (and a slightly higher or lower relative value of wood (or other tree products) could shift the balance). For the three wettest climates the positive effects of agroforestry on grain yield are accompanied by additional wood production and agroforestry is superior, unless the relative value of wood is at least 50% higher then we assumed here. The additional production of agroforestry is based on a more complete use of water: the fraction of rainfall draining from the profile is substantially (about 15-20% of rainfall) reduced by the tree crop combination,

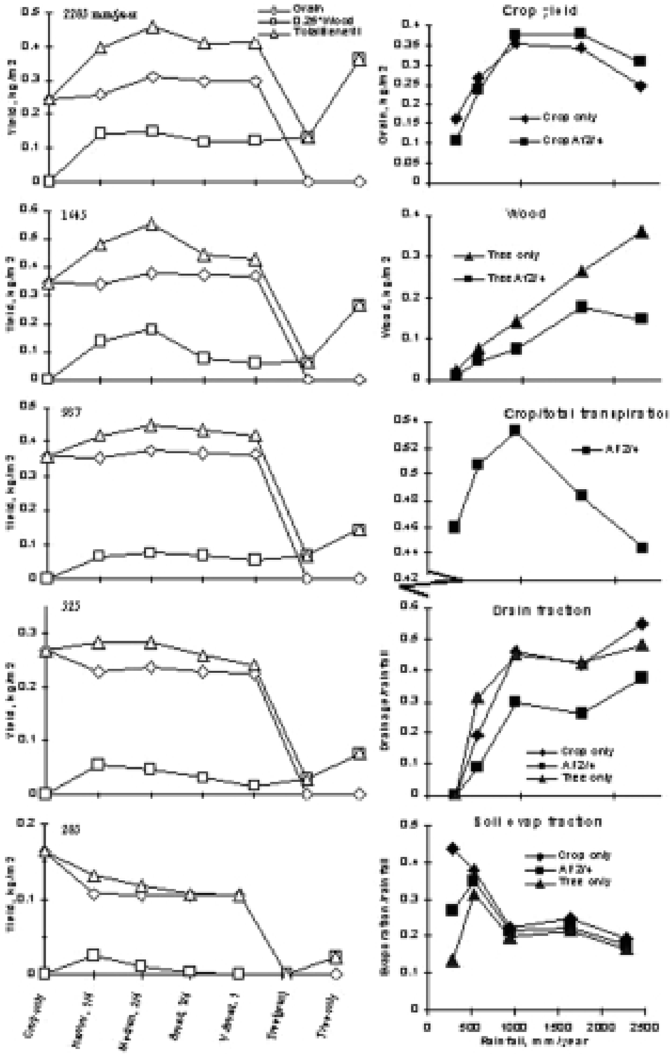


Figure 4.8 Calculations with the WaNuLCAS model of grain and wood production and water use for a range of annual rainfall conditions in an agroforestry system with isolated trees which are pruned when a crop is sown, resembling an early stage of a parkland system; production is accumulated over 2 years, involving 4 (at 2285 and 1645 mm/year) or 2 crops of 98 days duration, on a sandy soil with limited N mineralization from soil organic matter (for main parameter settings see text)

while model results for soil evaporation losses are intermediate between pure crop and pure tree systems

The share of the crop in total transpiration was always around 50% and peaked in the 1000 mm rainfall situation. Crop water use efficiency was highest at the driest site, as N limitations reduced it in wetter zones. For the tree water use efficiency was not affected by climate as its N fixation was not limited by drought.

As a whole, model calculations may present a reasonable correspondence with real world options, although no experimental data sets exist on the same agroforestry system at the same soil but widely differing rainfall conditions. Any of the effects mentioned here would vary with parameters such as soil depth, soil texture, tree canopy characteristics and rooting pattern or crop root length density, but the basic pattern of response to climate zones would remain determined by overall resource availability. Model results agree with conclusions about the perspective of simultaneous agroforestry systems from experimental evidence (Rao *et al*., 1997; Breman and Kessler, 1997). Mobbs *et al*. (1998) and Cannell *et al*. (1998) came to similar conclusions on the basis of the HYPAR model, which gives a more detailed treatment of aboveground processes and a similar, but less elaborate treatment belowground.

4.8 Model parameter sensitivity for P uptake

WaNuLCAS model was used to explore the effect of root density and presence of mychorriza on phosphorous uptake in agroforestry systems (van Noordwijk, *et al*., 1999)

The predicted P uptake for both tree and crop (Fig. 4.9A and B) respond to changes in root length density (Lrv) and mycorrhizal parameters and initial soil P content as one might have expected, with mildly negative responses to increased effective root length density by the other partner (tree or crop). The model's sensitivity indicates that reasonable estimates of effective root length density will be essential for a 'process-based' model. When rhizosphere modification is included (Fig. 4.9C and D), the results point to a clear effect of the synlocation parameter in deciding whether the net effect for the crop of trees with P mobilizing properties will be positive or negative.

4.9 Hedgerow intercropping: safety-net function of tree roots

The WaNuLCAS model can be used to estimate the tree root length density in the subsoil required for efficient functioning of a safety net (Fig 4.10). A practical definition of the safety net efficiency is the tree N uptake from the soil layers considered, as fraction of total output from this layer by leaching plus uptake. An additional output variable had to be created to capture this parameter.

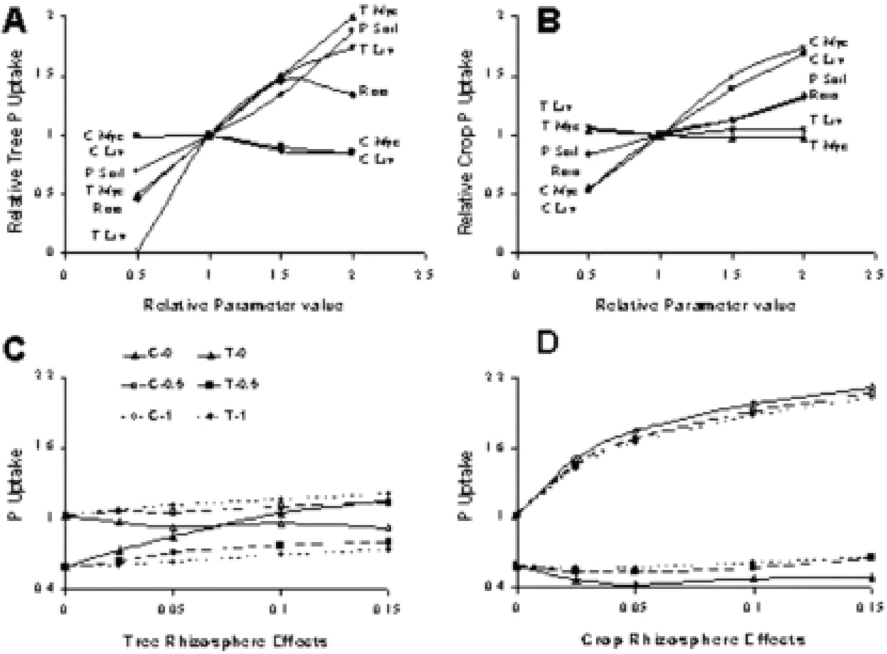


Figure 4.9 Preliminary calculations with the WaNuLCAS model after incorporating a P balance. A and B Sensitivity of predicted P uptake by tree (A (and crop (B) to changes in parameters for root length density T_Lrv and C_Lrv, respectively), mycorrhiza (C_Myc and T_Myc), soil P content (P_Soil) and rainfall. C and D. Effect on P uptake by tree (T) and crop (C) of rhizosphere modification by the tree (C) and crop (D), depending on the synlocation parameter (0 = only plant modifying rhizosphere benefits, 1 = benefits shared on basis of root length density)

WaNuLCAS calculations (Cadisch *et al*., 1997) (using version 1.1) where tree root length density in the subsoil was varied over the 0 - 2 cm cm^{-3} range indicated that about 25% of the N leaching below the crop roots can not be recovered (for the soil, climate and tree parameters used) by hedgerow tree roots as it occurs at times that the tree have no current unsatisfied N demand. A nearly linear increase was predicted in safety net efficiency (tree N uptake from the soil layers considered, as fraction of total output from this layer by leaching + uptake) between a tree root length density of 0 and 1 cm cm^{-3}. The model thus predicts that under conditions of continuous leaching a substantially higher tree root length density is needed than what would be adequate for near complete N uptake without a rainfall excess (Van Noordwijk, 1989; De Willigen and Van Noordwijk, 1987). Further data from trials in Lampung (Rowe *et al*., 1999), are in line with this model.

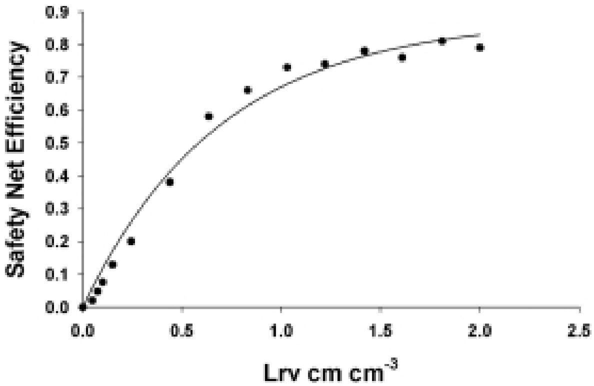


Figure 4.10 Use of the WaNuLCAS model to estimate the tree root length density in the subsoil required for efficient functioning of a 'safety net' (modified from) Cadisch *et al*. (1997); model runs were made with an N adsorption constant Ka of 0.2, reflecting a nitrate-dominated situation as can be expected at high soil pH values

4.10 Water and Nutrient Use efficiency in Agroforestry Systems

Farming systems purely based on annual food crops during and directly after deforestation generally lead to degradation of soil. Establishment of timber and/or fruit trees in cropped fields is feasible and offers better prospects in term of its sustainability. The efficiency of water and nutrient use in agroforestry systems can be used as an indicator of systems sustainability. In this study WaNuLCAS was used to assess the water and nutrient use efficiency in three alley cropping systems (Suprayogo, *et al*., 2002) The crop component is maize and the tree components are: *Paraserianthes falcataria, Hevea braziliensis* and *Swietenia mahagony*.

In this study water use efficiency is defined as: E_{water} (%) = (Tc + Tt)/R * 100, where:

E_{water} = water use efficiency
T_c = crop transpiration
T_t = tree transpiration
R = amount of rainfall

nutrient use efficiency is defined as: $E_{Nutrient}$ (%) = $(N_c + N_t)/(N_{Leach} + N_c + N_t) * 100$, where:

$E_{Nutrient}$ = Nutrient use efficiency
N_t = tree nutrient uptake
N_c = crop nutrient uptake
N_{Leach} = amount of nutrient leached

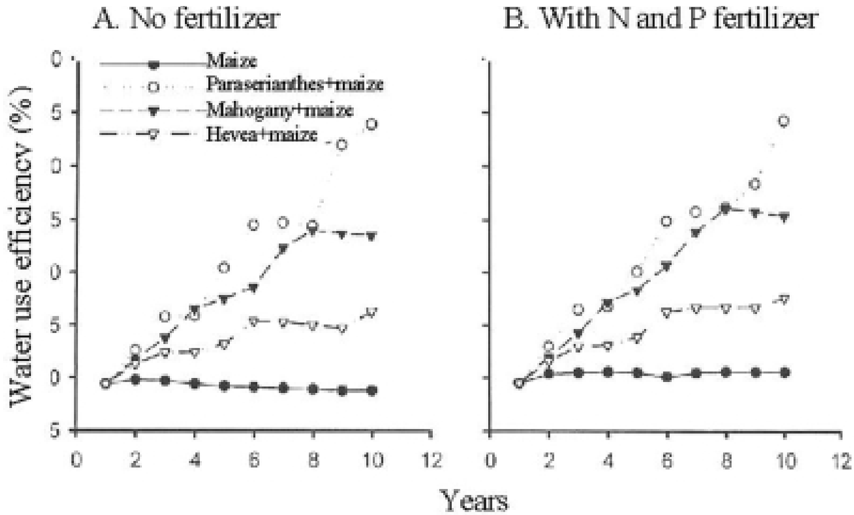


Figure 4.11 Water use efficiency at different agroforestry systems: maize monoculture, paraserianthes + maize, mahogany + maize and hevea + maize. (A) no fertilizer and (B) with N and P fertilizer

Result shows that water use efficiency in tree based systems tend to increase with increasing age of the tree (Figure 4.11). Paraserianthes-maize is the systems with highest water use efficiency while Hevea-maize is the systems with lowest water use efficiency. Presence of trees in the system also reduced runoff and increased supply to ground water stores.

N-use efficiency in tree-based systems also tends to increase with increasing age of the tree (Figure 4.12). Mahogany-maize is the systems with highest N-use efficiency while Paraserianthes-maize is the systems with lowest N-use efficiency. The use of N fertilizer caused the N-use efficiency to decrease since N leaching becomes higher. On the other hand, P-use efficiency tends to decrease with increasing age of the tree. This is because P is an immobile nutrient that stimulates accumulation of P in the soil producing low P leaching.

4.11 Management options for agroforestry parkland systems in Sapone (Burkina Faso): separating the tree-soil-crop interactions using WaNuLCAS

Trees in the parkland systems of West Africa provide food and income, but also interact with the grain crops. Competition and complementarity in

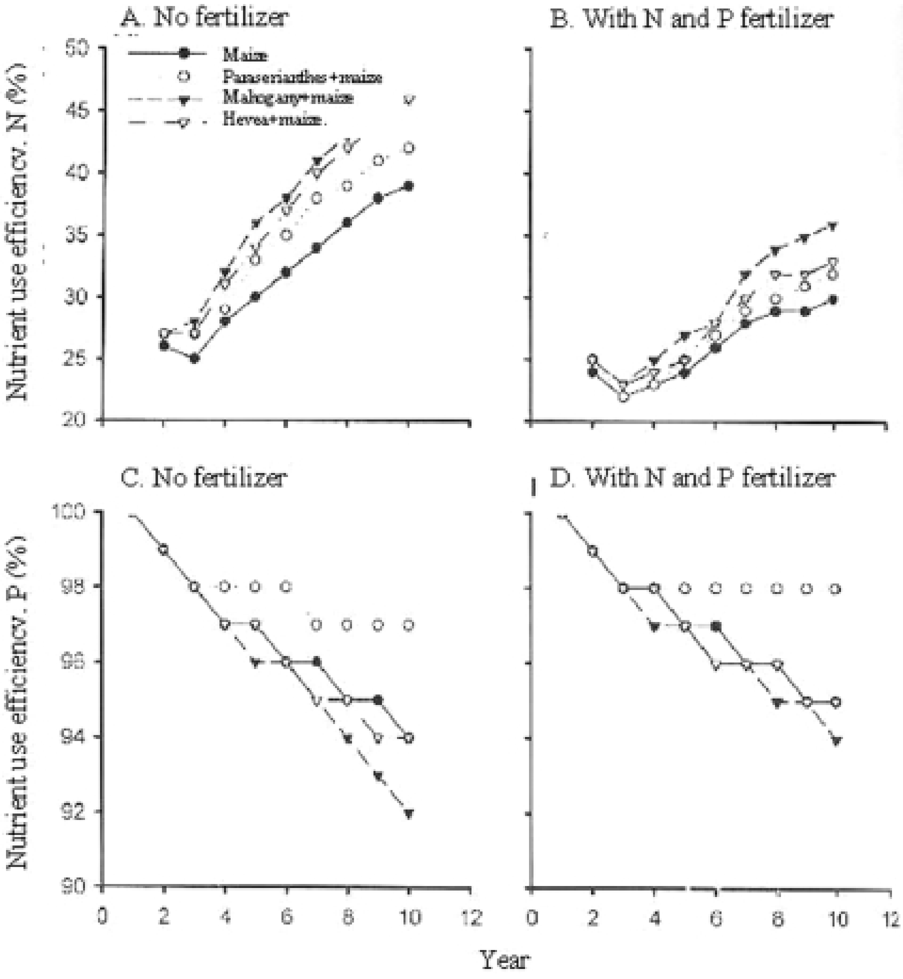


Figure 4.12 Nutrient (N and P) use efficiency in the different agroforestry systems: maize monoculture, paraserianthes + maize, mahogany + maize and hevea + maize. (A and C) no fertilizer and (B and D) with N and P fertilizer

resource use between the components of these systems need to be better understood. The effects of crown pruning of agroforestry parkland systems in terms of resource capture and utilization either were investigated in an agroforestry parkland system in Burkina Faso or was analysed using the Water Nutrient and Light Capture in Agroforestry Systems (WaNuLCAS) (Bayala, *et al.*, 2004).

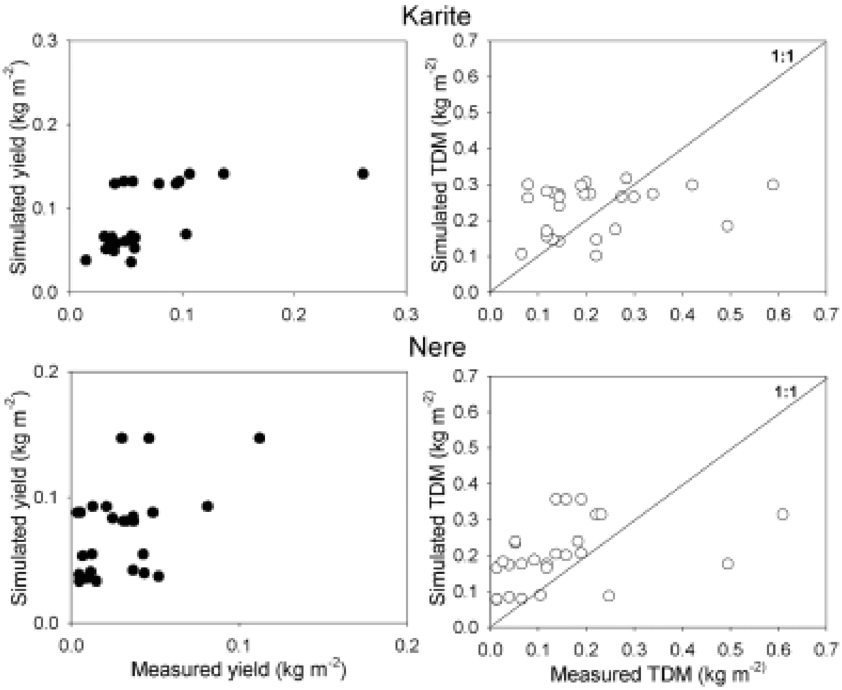


Figure 4.13 Scatter plots of measured and simulated crop yield and total dry matter (TDM) under karité (*Vitellaria paradoxa*) and néré (*Parkia biglobosa*) trees in a parkland agroforestry system in Saponé, Burkina Faso

The tree was focus on two species *Vitellaria paradoxa* C.F. Gaertn (karité) and *Parkia biglobosa* (Jacq.) Benth. (néré) with associated crops of *Pennisetum glaucum* (L.) (millet) and *Sorghum bicolor* (L.) Moench (sorghum). Three treatments of crown pruning (totally-pruning, half-pruning and no-pruning) were applied to karité and néré. The area under each tree was divided into four concentric tree influence zones before pruning the trees (Zones A: up to 2 m from the tree trunk, B: up to half of the radius of the tree crown, C: up to the edge of the tree crown and D: up to 2 m away from the edge of the tree crown).

Figure 4.13 shows crop performance for the various zones and pruning regimes tended to be overestimated, indicating that not all limitations occurring tin the field were adequately represented and / or that resource capture for the resources included in the model (light, water, N and P) was overestimated. Simulation with WaNulCAS indicated that the plant components differed in the key limiting factors. For the Karite, with a relatively shallow root system and ability to fix atmospheric nitrogen, water limitation dominated for (29%, 27% and 33% of the simulation period for unpruned, half-pruned and totally pruned trees, respectively). Water limitation was also found to restrict crop growth under this species (26% of the time in unpruned and half-pruned trees, and 30% of the growing season for totally pruned) trees. P limitation restricted crop growth only 8% of the season in unpruned and half-pruned trees and 4% in totally pruned trees. Water limitation under karite is probably due to its shallow root system indicating its high dependency on rainfall water and probable less access to the ground water table. For the Nere tree the main limitations were water (11 to 32% of the simulation time) and P (15 to 42 of the simulated time). Crop growth under Nere was mainly limited by P (32 to 50% of the simulated growing season) corroborate to the findings of Tomlinson *et al.* (1995) and Bayala *et al.* (2002).

4.12 Long time effect of Legume Cover Crop (LCC), sugarcane harvest residue (trash) and Bagas (sugarcane processing waste) on soil carbon and sugarcane yield

Ultisols is a typical soil type in North Lampung, Indonesia. It is low in soil organic matter content as well as N, P and exchangeable cations. It also has high concentration of Al and Mn. Thus, the main problem in soils of North Lampung is low fertility.

Soil organic matter is the key factor to soil fertility. One way to prevent more soil degradation is to maintain soil organic matter. Maintaining soil cover throughout the year, either by cover crop or by mulch, can do this. A continuous biomass is required to stabilize the organic matter content of the soil. According to Young (1989) about 8.5 Mg ha^{-1} annual input of aboveground biomass is required in order to maintain soil carbon content of 2%.

One of the main crops in North Lampung is sugarcane. Sugarcane yields tend to drop rapidly if there is no fertilizer input. A potential source organic input to the systems is sugarcane harvest residue (trash) and Bagas (sugarcane processing waste). Thrash is normally burnt after harvest and Bagas (sugarcane processing waste) is normally piled up around the sugarcane factory creating high risk of fire.

Brawijaya University-Indonesia had conducted an experiment to test the effect LCC, sugarcane harvest residue (trash) and Bagas (sugarcane processing waste) on sugar cane growth and production. The following applications of organic materials were tested on a soil that had been cropped for more than 10 years after forest conversion: (1) without organic materials as a control, (2) bagas 8 Mg ha^{-1}, (3) bagas 16 Mg ha^{-1}, (4) sugarcane trash (harvest residue) 8 Mg ha^{-1}. The whole plot was planted a mixed of legume cover crops (LCC) Mucuna pruriens var. utilis and Centrosema pubescens (1:1) and was given rock phosphate 1 Mg ha^{-1} at the first year and followed by sugarcane for another 2 years.

Based on this experiment, we simulate the systems using WaNuLCAS model to see the long-term effect of the organic inputs on soil fertility

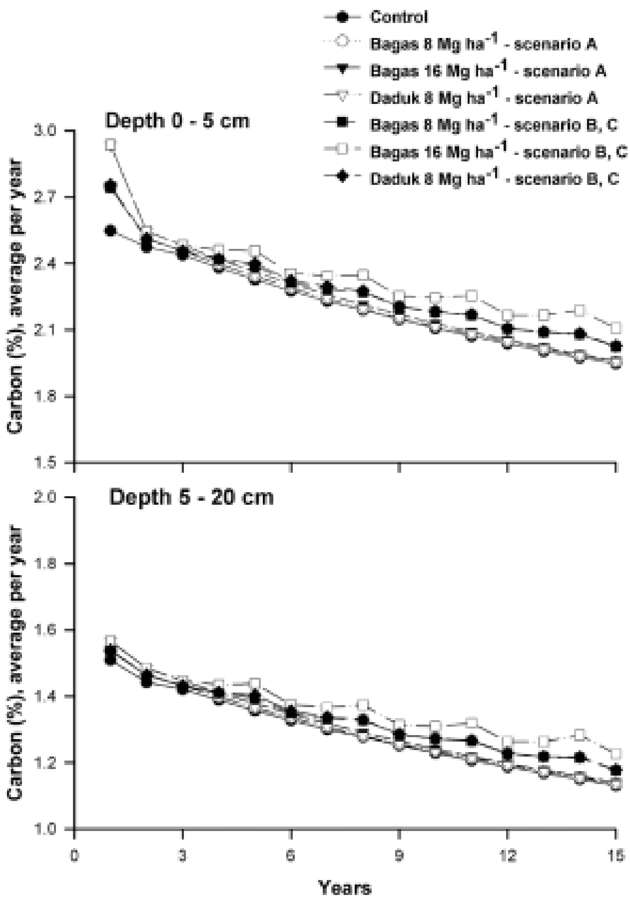


Figure 4.14 Soil organic matter content (average per year) at depth 0 - 5 and 5 - 20 cm of soil

(Hairiah, *et al.*, 2003). Three different scenarios were used: (A) external organic input given only at first year and N and P fertilizer every years with similar dosage, (B) external organic input gave every three years and N and P fertilizer every years with same dosage, (C) external organic input gave every three years and N and P fertilizer every years with different dosage (ratio dosage / years = 1.2:0.9:0.9 from default value and start from third years).

The simulation predicted that additional organic input do not significantly affect the long-term amount of organic carbon of the systems (Figure 4.14). The organic matter content at 0 - 5 cm depth decrease by 0.04 - 0.07% per year, which is faster compare to 0.02 - 0.03 % per year at depth 5-20 cm.

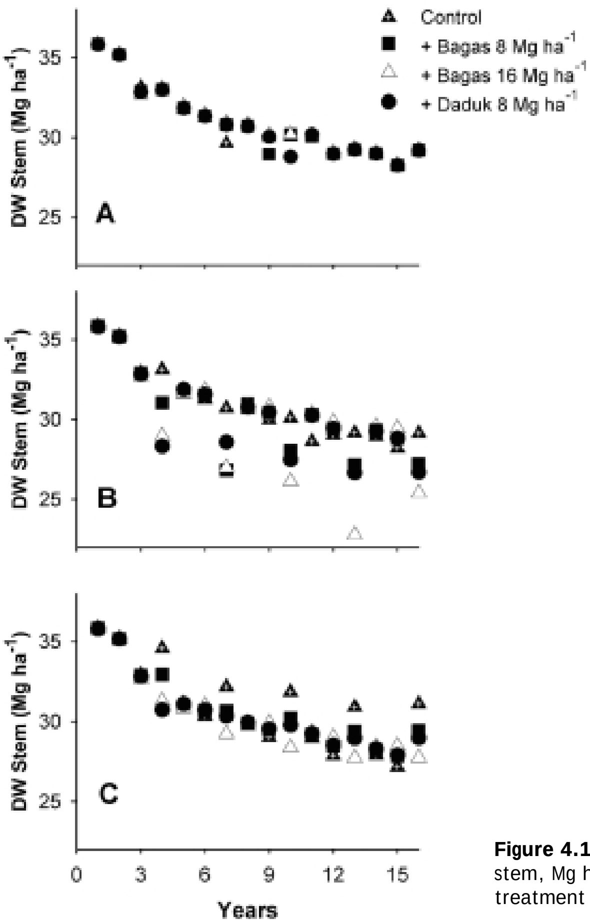


Figure 4.15 Sugarcane yield (in dry weight stem, Mg ha^{-1}) for 16 years in different treatment and scenario

The results also predicted that application of sugarcane residues to the soil lead to a slower declining rate of sugar cane yield if accompanied by application of N fertilizer (Figure 4.15). Without N fertilizer application, returning sugarcane residues will cause N immobilization in the soil causing a decrease in sugarcane yield.

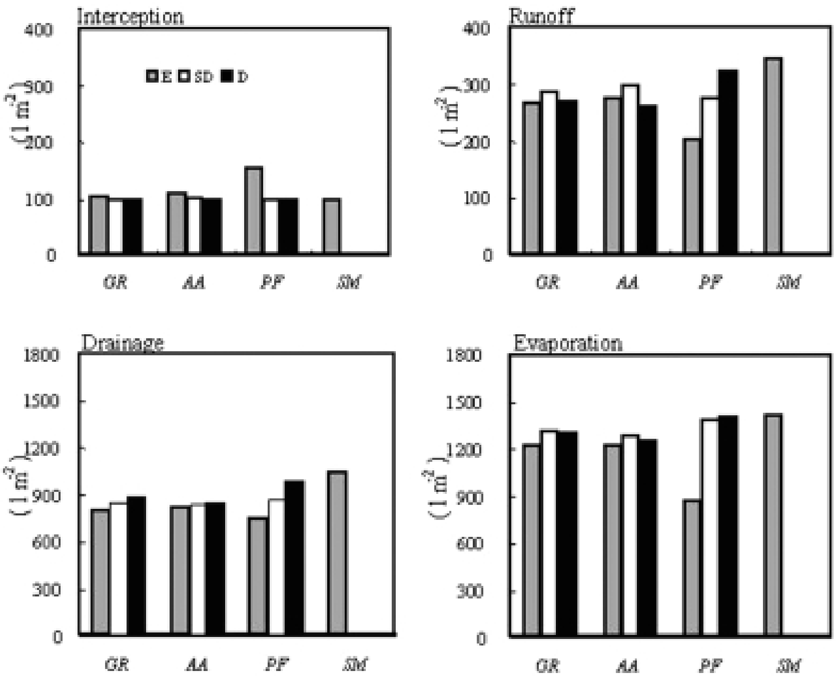
4.13 The effect of agroforestry systems based on differing leaf phenologies on water balance and tree and crop growth

In Thika and NaroMoru, West of Mt. Kenya introduction of tree species into the cropping systems might aggravate the crop since water limitation is an important factor for the crop performance and yield. The differences of crop performance and yield may have relation to the tree water uptake that is corroborate to the tree leaf phonologies. The WaNuLCAS model was used to simulate water balance of the agroforestry systems based on differing leaf phenologies (Muthuri, 2003). The tree was focus on three species G. robusta, A. acuminata and P. fortunei associated with maize. G. robusta is evergreen, A. acuminata is semi-deciduous and P. fortunei is deciduous in term of tree water uptake.

Figure 4.16 and 4.17 shows the components of the water balance by the trees and crops using different leaf phenology for the Thika and Naro Moru site. The simulations of the water balance between Thika and Naro Moru site shows was not too different. Changing leafing phenology from evergreen, through semi-deciduous to deciduous generally decreased water uptake by the trees and interception of rainfall by all three trees species. Simulated total water uptake was never greater in all agroforestry systems than in sole maize, although the estimated water uptake by the crop component in the agroforestry systems was close to that for sole maize, especially when the deciduous leafing phenology scenario was adopted.

4.14 Safety net efficiency - effect of root length density and distribution

The presence of hedgerow tree in the crop field may lessen nutrient leaching. For nutrients of higher mobility leaching could be reduced if tree have a relatively dense root system beneath the crop root zone (a safety net). Cadisch *et al.*, 1997 have explore how such safety net function may depend



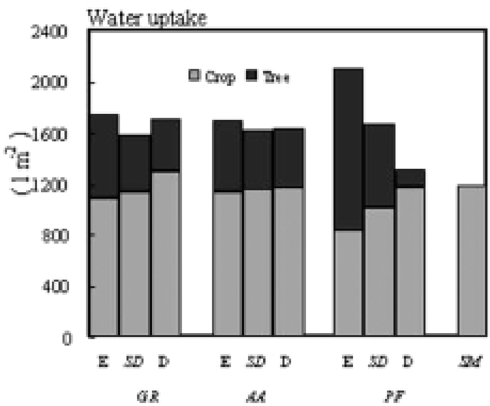


Figure 4.16
Simulated values for water balance components in (SM) sole maize and agroforestry systems containing (GR) G. robusta, (AA) A. acuminata and (PF) P. fortunei in five year simulation involving (E) evergreen, (SD) semi deciduous and (D) deciduous leaf phenology scenarios at Thika

on tree root length density in the layer underneath the crop root zone. WaNuLCAS was used to test the positive (safety net functions) and negative (competition for water and N) impacts of simultaneous tree roots on maize yield by separating relative tree root distribution from absolute root length density for topsoil and subsoil (van Noordwijk and Cadish, 2002).

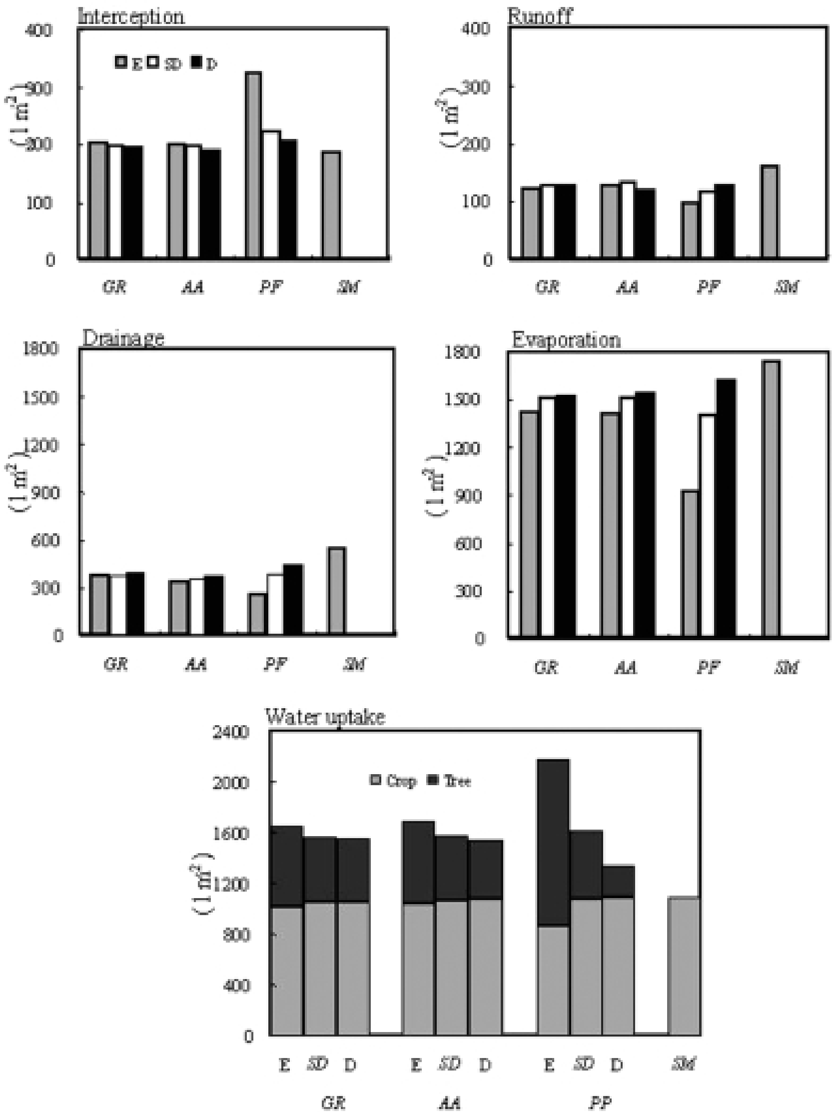


Figure 4.17 Simulated values for water balance components in (SM) sole maize and agroforestry systems containing (GR) G. robusta, (AA) A. acuminata and (PF) P. fortunei in five year simulation involving (E) evergreen, (SD) semi deciduous and (D) deciduous leaf phenology scenarios at Naro Moru

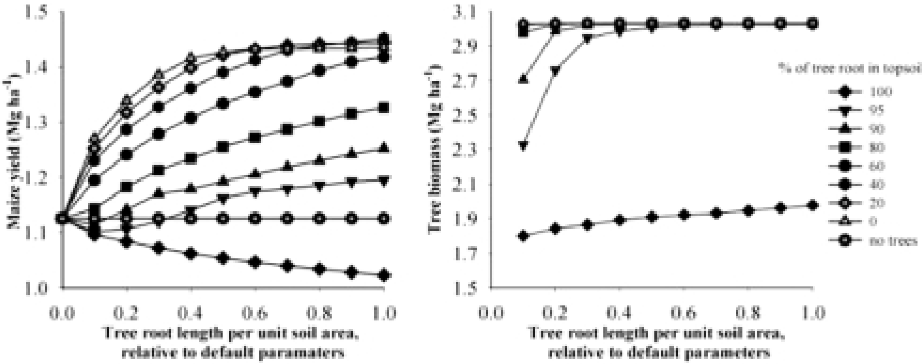


Figure 4.18 Predicted maize yield (A) and tree biomass (B) for the default rainfall situation (2318 mm year^{-1}), when relative distribution of tree roots with depth as well as total amount of tree roots are varied independently. Whereas the 'default' tree roots system had 21.5% of its roots in the top layer, a series of data was made that had 0 - 100% of its roots in the top layer and the remainder allocated to the deeper layers in proportion to the root length densities of the default case (the relative distribution over the four zones with increasing distance to the tree was not modified). For each of these root distributions, the total amount of roots was varied from 0.1 - 1 times the default, while maintaining the relative value.

Figure 4.18 shows that negative effect of the tree can be expected from trees that have all their roots in the topsoil, and from trees with only 0 - 10% of their roots in the subsoil, at low overall tree root length. These same relative tree root distributions at higher total root length (i.e. higher absolute root lengths in both top and subsoil) can have a moderate positive effect on maize yield, while tree root systems with 20% or more of their roots in the subsoil were consistently positive for crop, the higher the total root length, the more positive the impact on maize.

A remarkable feature of these results is that at default value for total root length, the tree root systems with 60% of their roots below the top soil led to (slightly) higher maize yields, than those with more (up to 100%) in the subsoil, while at total root systems size the 100% in subsoil (0% in top soil) was better for the maize. Although this effect is much too subtle to be recognized in any field data, it seems counter-intuitive.

4.15 Tree root systems dynamic - root functional and local response

Simulation models can represent belowground resource capture process at different levels of sophistication (van Noordwijk and De Willigen, 1987):

1) Level 0.
   models 'without roots' using empirical resource capture efficiency coefficients for the relation between water and nutrient supply in the soil and the dynamics of plant growth,
2) Level 2.
   models that differentiate between soil layers and use empirical data on relative root distribution to predict resource capture potential in each zone; root distribution can be schematised via an exponential decrease with depth (Jackson *et al.*, 1996) or its 2-dimensional elliptical variant (Van Noordwijk *et al.*, 1995), or they can be provided as 'independent' parameters for each layer or zone; change of root length densities with time can be imposed on the basis of crop age,
3) Level 3.
   models that consider plants as organisms with the capacity to adjust the total amount of roots to the internal balance between above and belowground resource capture, and the location of new root growth to the parts of the root system with the best opportunities for uptake of the resource that is most limiting overall plant growth.

WaNuLCAS model can predict competition for water and nutrients between trees and crops at 'level 0' and 'level 1'. It can also be used at 'level 2' using spatial root distribution that restrictedly follows the exponential-decrease-with-depth or elliptical distributions. Stress of nutrient (N, P) or water is an important factor for the crop growth. When nutrient (N, P) or water stress occurs, the relative allocation of growth reserves to root can increase quickly.

The WaNuLCAS model was used to explore the change of root patterns due to local response (van Noordwijk, *et al.*, 2003). A series of simulations was made for a moderately deep soil (1 m) with an annual rainfall of 1000 mm. Rainfall patterns ranged from '1 = every day 3 mm of rain' and '2 = every second day 6 mm', to '6 = every 32 days 96 mm'. As the potential evapotranspiration was assumed to be 4 mm day^{-1}, this environment would not provide enough water to avoid water stress, even if all rainfall were to be fully used. Figure 4.19 shows the rainfall patterns lead to situations of permanent moderate stress (rainfall pattern 1), alternations of sufficient water and severe water shortage (rainfall patterns 5 and 6) or intermediate patterns. In the overall water balance, with a decrease in the number of rainy days (through patterns 1 to 6), a decrease in the values for the interception and soil evaporation terms can be noted, while the contribution to groundwater (deep infiltration) and runoff increases but remains small in absolute value.

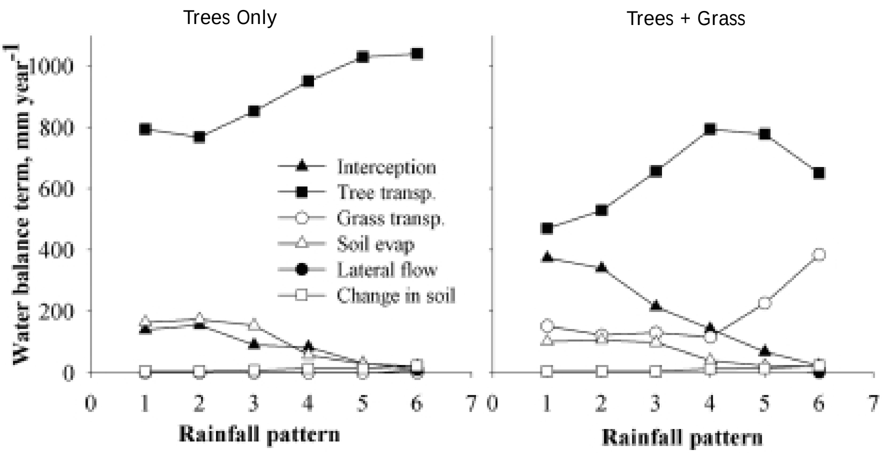


Figure 4.19 Water balance for a range of WaNuLCAS simulations, in the absence of functional or local response of the tree, with and without a grass sward

Cumulative tree water use tends to increase through rainfall patterns 1 to 6. If a grass sward is added to the simulations, canopy interception increases and thus the amount of soil water available to either tree or grass is reduced. The grass water use is predicted to benefit more from rainfall patterns 5 and 6 than the tree causing a bell-shaped response curve for the tree.

A sensitivity analysis was carried out on the two key parameters for the functional shoot/root balance and root distribution: 'Root_Allocation_Responsiveness' and 'local response'. Higher values of 'Root_Allocation_Responsiveness' lead to a more rapid shift of current growth resources to roots, at the expense of shoot growth, when the total uptake of water and/or nutrients falls short of current 'demand'. With increasing 'local response', root distribution shifts towards the soil layer and spatial zone in which roots are most successful (per unit root length) in taking up the most limiting resource.

'Local response' is simulated in WaNuLCAS by a gradual change in the parameters of the elliptical root distribution, and constrained by the total new length of roots that can be produced with the carbohydrates allocated. The intensity of change depends on the T_DistResp parameter and on the degree to which effective uptake per unit root length of the currently limiting resource differs between soil layers and zones. If roots in deeper layers are more effective (e.g. in case of water stress), the root distribution can shift to a more gradual decrease of root length density with depth (or even an inverse

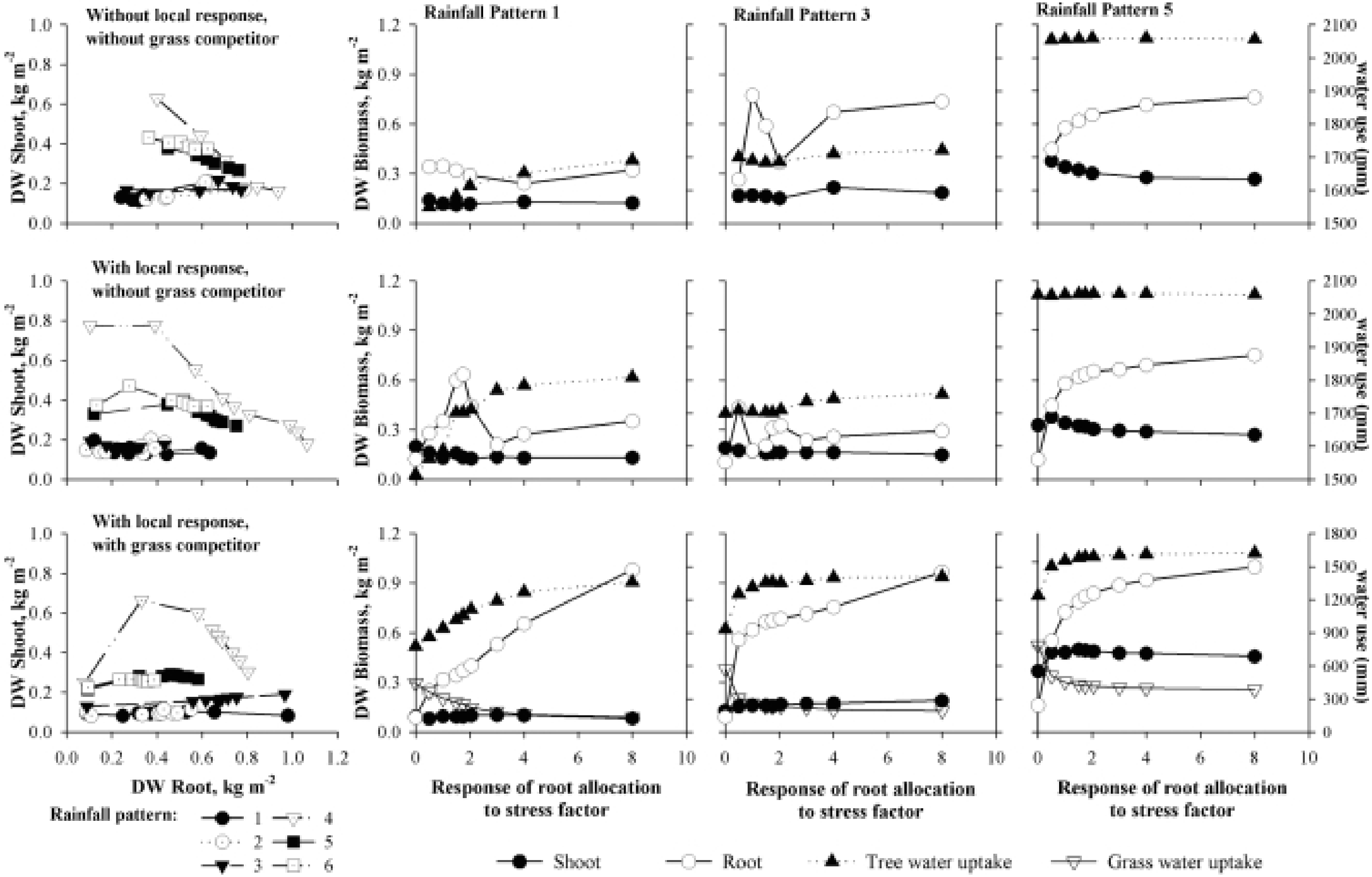


Figure 4.20 Simulation results for shoot and root dry-weight (DW) biomass and tree (and grass) water use, for three rainfall patterns and a range of parameter values for the 'root_Allocation_Responsiveness' parameter (see explanations in text). Simulations include situations with and without 'local response' (see text), and with and without competition from a grass sward

pattern…), if roots in topsoil are more effective (e.g. when P uptake is overall limiting plant growth and the topsoil has sufficient water content to keep the P mobile) roots will expand (mainly) in topsoil.

The general patterns of root and shoot response in the simulations can be understood from the re-wetting patterns of the soil (Figure 4.20). In the absence of a competitor, a stronger root allocation leads to a larger root system, but only in rare situations to a larger shoot biomass or total water use. For rainfall patterns 1-4 the 'local response' rules lead to a shallower tree root system, as the rainfall events are insufficient to rewet the whole soil profile and superficial roots are thus more effective in water uptake than deep ones. For rainfall pattern 5 and 6, however, the local response rule leads to a deeper root system. In the presence of a competing grass sward, total water use by the tree is expected to decrease substantially and the tree biomass will consequently be lower. A marked difference with the previous simulations, however, is that now a larger root allocation can actually increase tree water use and shoot biomass. The competitor is predicted to enhance the increase in the fraction of tree roots in the topsoil for rainfall pattern 1-4. For rainfall pattern 5 the presence of a grass sward is predicted to drive the tree root to a more superficial pattern, rather than the deeper pattern of the monoculture.

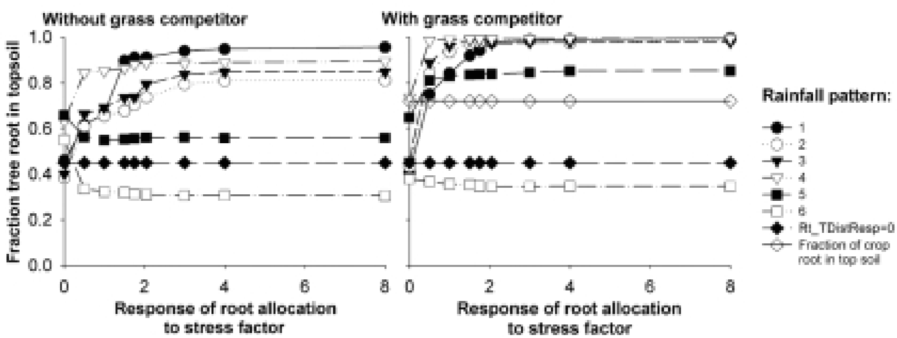


Figure 4.21 Relative tree root biomass in the upper 25 cm of the soil profile for a range of values of the factor that governs the response to stress of the biomass allocation to roots, with (right) and without (left) a competing grass; the grass is assumed not to show a functional or local response, so it has a constant fraction of its roots in the topsoil; the line Rt_TdistResp = 0 indicates a situation without 'local response', so the 'response to stress' can modify total root biomass, but not root distribution for this setting.