AGRIVITA VOLUME 32 No. 3 OCTOBER-2010 ISSN : 0126-0537

AGROFORESTRY INTERACTIONS IN RAINFED AGRICULTURE: CAN HEDGEROW INTERCROPPING SYSTEMS SUSTAIN CROP YIELD ON AN ULTISOL IN LAMPUNG (INDONESIA)?

Didik Suprayogo[1*)], Kurniatun Hairiah[1)], Meine van Noordwijk[2)] and Georg Cadisch[3)]

[1)] Soil Science Department, Faculty of Agriculture, Brawijaya University
Jl. Veteran Malang 65145 East Java Indonesia
[2)] World Agroforestry Centre Indonesia
Jl. CIFOR, Situ Gede Sindang Barang, Bogor 16680. P.O. Box 161, Bogor 16001 Indonesia
[3)] Institute of Plant Production and Agroecology in the Tropics and Subtropics,
University of Hohenheim, 70593 Stuttgart, Germany
[*)] Coressponding author Phone : +62-341-553623 E-mail: suprayogo09@yahoo.com

Recieved: January 24, 2010/Accepted: September 12, 2010

ABSTRACT

The productivity of rainfed agriculture land developed on Ultisols is limited by physical and chemical constraints. These problems can be solved and consistently high yields obtained only by the development of comprehensive management systems. In the 1980s, hedgerow intercropping was promoted initially for improving soil fertility and sustainability of crop production on nutrient-depleted soils. However the previous enthusiasm for hedgerow intercropping is unsupported by scientific evidence and its labour demand too high. The question remains, is there a window of opportunity where the biophysical principle of hedgerow intercropping is sound? Research to compare the long-term performance of crops and trees in hedgerow intercropping and monocluture cropping is needed. This research has been conducted at long-term field experiment station at the BMSF-Project, Lampung, Indone-sia. The experiment site had non-nitrogen-fixing peltophorum (PP), nitrogen-fixing gliricidia (GG) and alternate peltophorum and gliricidia (PG) hedgerow intercropping and maize/ groundnut monoculture (C) treatments. We concluded that the net interactions related to soil fertility and competition for growth resources in peltophroum were positive for crop yield in PP and PG but negative for GG. Even so, the PP and PG systems resulted in similar yields as monocropping; however, hedgerow intercropping considerably improved soil fertility attributes.

Keywords: Agroforestry, crop yield, ultisols, tropics, sustainable

INTRODUCTION

Productivity of acid upland soils (Ultisols) in the humid climate of the tropics can be sustained and consistently high yields obtained, only by the development and introduction of comprehensive management techniques that address the physical and chemical constraints.

The high prevailing temperatures and the resulting rapid chemical, physical and biological processes mean that the penalties paid for imbalances in the solid, liquid and gaseous phases of the soil are much larger than in temperate regions (Von Uexkull, 1986). In the 1980s, hedgerow intercropping was promoted as an integrated approach to maintaining soil fertility and crop production on nutrient- depleted soils in the humid tropics. As a 'simultaneous' system it might replace the 'sequential' bush fallow-crop rotations (Rao *et al*., 1998).

Evidence for improvement of soil fertility in hedgerow intercropping was reviewed by Rao *et al*. (1998), recognizing chemical, physical and biological effects. The chemical aspect of soil fertility improvement is due to the benefit of regular additions of hedgerow prunings to the soil, which increases the dynamic pools of soil organic matter (SOM), and plant-available soil nutrients. The increase or maintainance of plant-available soil nutrients is due to four major mechanisms: (1) nitrogen input into the system through biological nitrogen fixation (BNF) in the

Accredited B, SK No.: 65a/DIKTI/Kep/2008

case of N_2-fixing species; (2) reduced soil erosion; (3) reduced leaching of nutrients, and (4) uptake of soil nutrients from deep soil layers that are beyond the crop root zone ('nutrient pump') and recycling them to the soil surface via prunings ('safety net')(van Noordwijk and Cadisch, 2002; Cadisch *et al*., 2004). Hedgerow intercropping, as compared with monocropping, has been shown to considerably improve soil physical properties (Suprayogo, 2000) i.e. there has a beneficial effect on soil structure and hence increased macroporosity. The impact of fine tree roots on creating more-stable soil aggregates was suggested by Lal (1989a); large soil channels will also be formed by tree roots as found by Rowe (1999) and their effect noted by van Noordwijk *et al.* (1991). Other improvements in hedgewrow intercropping compared tro monoculture are lower soil bulk density (Suprayogo, 2000), lower resistance to penetration, increased soil porosity (Lal, 1989b) and reduced surface sealing (Hulugalle and Ndi, 1993). The consequence of these changes, using macro-scale field measurements, was that soil-water macropore flow was increased in hedgerow intercropping systems (Suprayogo, 2000). During periods of heavy rainfall, water flowing rapidly through macropores will contain relatively lower concentrations of solutes than that which has accumulated from micropores.

Soil macrofauna (especially earthworm) and root activity had positive effects on the soil fertility through improving soil structure and, in turn, soil water relations and nutrient availability to crops (Rao *et al*., 1998). Bringing typical 'fallow functions' to act simultaneously with food crop production appears to be technically feasible.

However Sanchez (1995) concluded that the previous enthusiasm for rapid on-farm adoption of hedgerow intercropping had been unwarranted, based on analysis of numerous experiences throughout the tropics. He presented data collected by Ong and van Noordwijk (ICRAF, 1995) on eight hedgerow intercropping systems. In this work the net effect (I) of intercropping was split into a positive facilitation of fertility (F) through the regular supply of prunings to the soil, and a negative competitive effect (C) of the trees capturing resources that would have otherwise been available to the crop. Further expansions on the simple equation (I = F + C) were subsequently proposed (Cannell *et al*., 1996). Across tree species with different growth rates F and C tend to be correlated and an adjustment of hedgerow spacing to reduce C also reduces F. Among the data of the early rounds of hedgerow intercropping experiments, the experience with Peltophorum hedgerows in Lampung appeared to combine relatively high F with low C terms, yielding a net positive effect (van Noordwijk *et al.*, 1995). Further analysis of this system is therefore of interest, even if the labour requirements for pruning activities in the current hedgerow intercropping system are too high to be economically feasible.

The questions remains, is there a window of opportunity where hedgerow intercropping is, at least from a biophysical perspective, beneficial by de-linking the fertility and competitive effect? The effect of hedgerow intercropping on crop yields can be positive or negative depending on the climate and soil conditions (Rao *et al*., 1998). In the humid tropics (rainfall > 2000 mm), they showed that maize (*Zea mays*) and taro (*Colocasia esculenta*) did not benefit from hedgerow intercropping systems in four out of eight trials, but interestingly bean (*Phaseolus vulgaris*) and cowpea (*Vigna unguiculata*) yields invariably increased. In Peru, on Typic Paleudults characterised by high acidity and Al toxicity, hedgerow intercropping systems maintained yields of Al-tolerant rice and cowpea crops at 1 and 0.5 t ha^{-1}, respectively, for many seasons (ICRAF, 1995). In contrast to declining maize yields in sole-crop systems, hedgerow intercropping systems produced higher yield over a long period in the acid soils of Indonesia (van Noordwijk *et al*., 1995). In reviewing the choice of tree species for hedgerows, Rao *et al.* (1998) concluded that *Leucena leucocephala* and *Gliricidia sepium* were well suited for base-rich soils, whereas *Calliandra calothyrsus*, *Acacia auriculiformis*, *Peltophorum dassyrrachis*, *Dactyladenia barteri*, *Erythrina poeppigiana*, *Leucaena diversifolia* and *Inga edulis* were suited to acid soils in specific climatic conditions.

The specific objective of this paper was to compare the long-term performance of crops and trees in hedgerow intercropping systems and monoculture cropping on an ultisol in Lampung. The objective was to test our hypothesis that trees with a small competitive effect per unit fertility improvement due to their above and belowground architecture and growth habits can sustain long term productivity of upland soils for food crops by using hedgerow intercropping systems.

MATERIALS AND METHODS

Site Description

A field experiment was conducted as part of Experiment 17 of the Biological Management of Soil Fertility Project (BMSF-Project), Karta (4°31' S, 104° 55' E), Kotabumi, Lampung, Indonesia. The experiment 17 site was established in 1985 with peltophorum (PP), gliricidia (GG) and alternate peltophorum and gliricidia (PG) hedgerow cropping systems and maize monoculture (C) treatments. Annual rainfall figures between 1975 – 1998 indicated an average rainfall of 2529 mm per year with a minimum recorded annual rainfall of 1575 mm (during an Elnino event, 1997) and a maximum recorded annual rainfall of 3386 mm (during La Nina event, 1998). The amounts of rainfall during the 1997/98 and 1998/1999 maize cropping seasons were 1234 mm and 650 mm respectively, and for groundnut, 818 mm and 531 mm respectively. On the climatic map of Oldeman *et al.* (1979) the project site is in the climate zone C2. This zone is characterised by 6 consecutive wet months (at least 200 mm precipitation) and three dry months (less than 100 mm precipitation). The wet season usually occurs from November to April, and the dry season occurs between June to September. The soil is classified as a Plinthic Kandiudult (Soil-Survey-Staff, 1992). Al-toxicity is probably the major plant-growth constraint, and is accompanied by deficiencies of the major nutrients. The percentage Al-saturation of the exchange complex is 20% in the topsoil and almost 60% in the subsoil, of which the latter is stated as high, but not extreme (Van Der Heide *et al*., 1992).

Monitoring of Tree Biomass and Crop Yields

The biomass residue and grain yields of maize presented in this paper are from two sequential periods of experiments. During the first period (from 1993/1994 to 1996/1997 cropping seasons) the experiment was set up with a hedgerow intercropping system without fertiliser application and was compared with monoculture maize treated with 45 kg N ha^{-1} and 90 kg N ha^{-1}. The maize was harvested at 17-02-94 (first crop season: December - February), 16-07-94 (second crop season: March - May), 18-02-95 (first crop season), 08-07-95(second crop season), 06-02-96 (first crop season), 18-06-96 (second crop season) and 29-01-97(first crop season). No result is presented for the 1996/1997 second crop season, because the plot was planted with *Mucuna utilis* as cover crop to improve the soil fertility and prepare for the "safety-net" experiment during the 1997/1998 cropping season. These data were collected from unpublished database of the BMSF-Project. During the second period (from 1997/1998 to 1998/1999 cropping seasons) both the hedgerow intercropping and monoculture systems received 90 kg N ha^{-1} of urea fertiliser where the "safety net" experiment was carried out to test the interception by tree roots below the crop root zone of leaching nutrients that might otherwise be lost from the system. In this second period, the maize was harvested at 14-03-98, and 15-02-99. The second crop for this period was groundnut. The groundnut was harvested at 29-06-98 and 08-06-99. Biomass fresh weight and grain yield of maize or groundnut were determined from a 12 m x 6 m area (crops from 3 alleys with 4 m width for each alley and 6 m length of alley) and the samples were separated for each row of maize or groundnut. The distance of maize and groundnut rows were 0.7, 1.35, 2 m (0.65 m row distance) and 0.5, 1.0, 1.5, 2 m (0.5 m row distance) from the hedge respectively. Sub samples were dried at 65 °C and weighed for dry matter measurement.

The gliricida hedges were pruned at 02-11-93 (Fallow phase (F)), 17-01-94 (Crop growing period phase (CGP)), 06-04-94(CGP), 07-06-94 (CGP), 13-11-94 (F), 14-01-95 (CGP), 26-05- 95 (CGP), 25-10-95 (F), 22-12-95 (CGP), 11-03-96 (CGP), 06-05-96 (CGP), 11-10-96 (F), 26-10-96 (CGP), 18-12-96 (CGP), 03-12-97 (F), 08-01-98 (CGP), 22-03-98 (CGP), 12-05-98 (CGP), 12-11-98 (F). 06-01-99 (CGP), 24-02-99 (CGP), and 26-04-99 (CGP). Due to their slower canopy regrowth, the peltophorum hedges were pruned less frequently at 02-11-93 (F), 06-04-94(CGP), 13-11-94 (F), 14-01-95 (CGP), 25-10-95 (F), 11-03-96 (CGP), 11-10-96 (F), 18-12-96 (CGP), 03-12-97 (F), 08-01-98 (CGP), 22-03-98 (CGP), 12-11-98 (F), and 24-02-99 (CGP).

Fresh weight of biomass of peltophorum or gliricidia were determined from a 6 m x 16 m area (4 rows of hedges with 6 m length of each hedge) in 1993 to 1997, and 12 m x 24 m area (3 alley crops and 4 m width for each alley with 24 m length of alley) in 1998 and 1999. Hedges were lopped at a height of 75 cm using sharp knives. Leafy biomass and succulent stems were separated from woody stems (> 2mm diameter, removed for firewood) and the samples were separated and then weighed for each row of hedge. Sub samples were dried at 65 ^{o}C and weighed for dry matter measurement.

Statistical Analysis

One way analysis of variance was carried out for tree biomass, maize and groundnut biomass and their yields with 4 cropping systems treatments and 2 blocks using Genstat Version 5.0. (Payne, *et al.,* 1987).

Simulation of Pruning Biomass and Crop Yields

WaNuLCAS model version 2.0 (van Noordwijk and Lusiana, 1999) that explore Water Nutrient and Light Capture in Agroforestry Systems was used to relate the water balance of the different cropping systems toi the expected downward movement of miobile nutrients and the opportunities for their capture by tree and crop roots. Site specific files for Lampung were made for climate data, soil characteristics and cropping systems.

The peltophorum + maize/groundnut, gliricidia + maize/groundnut hedgerow inter-cropping systems and maize/groundnut monocropping system from the BMSF field experiment during the 1997/1998 crop growing period were used as scenarios in the simulations of carbon, water and nutrient balance as well as crop yield. The input parameters for WaNulCAS simulation are described in van Noordwijk and Lusiana, (1999). The following output of the simulations were recorded: (1) current aboveground crop biomass and storage component of crop biomass (crop yield) in each zone (kg m^{-2}), (2) current biomass in tree canopy (kg m^{-2}), (3) the effect of water and nitrogen restriction on crop growth in each zone (0 = no growth, 1 = no stress) and (4) the current amount of carbon and nitrogen in the soil organic matter (SOM) pool (g m^{-2}). The data on crop biomass and yield, tree biomass, the effect of water and nitrogen deficits on crop growth, tree biomass and the current amount of carbon and nitrogen in the SOM pool, were presented using a line and scatter plot on Sigma Plot Version 4.0.

RESULTS AND DISCUSSION

RESULTS

Performance of Trees

The performance of the tree species, in terms of total biomass (dry weight basis) incorporated into the soil in the form of pruning is presented in Table 1 for six consecutive seasons (1993/1994 to 1998/1999). During the dry season 1994, an accidental plot fire reduced the biomass of the trees during the fallow period. In the 1996/1997 cropping season, plots were only planted with maize during the first growing season, resulting in a longer fallow period in comparison to the years when maize was planted two times consecutively. During the maize growing period, excluding pruning data from the 1996/1997 cropping period (as plots were pruned only once at early of maize growth), the pruning biomass of peltophorum in

PP was the lowest (1.70 t ha^{-1} on average ranging from 0.97 t ha^{-1} to 2.63 t ha^{-1}) compared to gliricidia in GG (4.83 t ha^{-1} on average and ranging from 3.82 t ha^{-1} to 6.81 t ha^{-1}) and peltophorum + gliricida in PG (4.06 t ha^{-1} on average and ranging from 2.90 t ha^{-1} to 4.83 t ha^{-1}). During the fallow period (dry season), excluding pruning data from 1994 (low pruning yields due to accidental burning) the pruned biomass of gliricidia in GG was the lowest (3.10 t ha^{-1} on average and ranging from 1.44 t ha^{-1} to 4.25 t ha^{-1}) compared to peltophorum in PP (5.79 t ha^{-1} on average and ranging from 4.60 t ha^{-1} to 6.62 t ha^{-1}) and peltophorum + gliricidia in PG (4.90 t ha^{-1} on average and ranging from 3.20 t ha^{-1} to 5.69 t ha^{-1}). From 1993/1994 to 1998/1999, total accumulated and average pruned biomass among the hedgerows was similar, with 40.30 t ha^{-1}, 42.20 t ha^{-1}, 48.00 t ha^{-1} and 7.24 t ha^{-1}, 8.42 t ha^{-1}, 9.27 t ha^{-1} for peltophorum in PP, gliricidia in GG and peltophorum + gliricidia in PG respectively.

Table 1. Pruned biomass of hedgerow trees for 6 seasons (1993/1994-1998/1999)

Cropping season	Phase	Pruned biomass (t ha^{-1}) from tree species or hedgerow systems of				
		Peltophorum	Gliricidia	Peltophorum + Gliricidia	SED	$F_{pr.}$
1993/1994	Fallow	6.62	4.25	5.34	1.44	0.425
	CGP[a)]	1.23	6.81	4.90	0.87	0.044
1994/1995	Fallow[b)]	1.85	1.15	1.93	0.12	0.035
	CGP	1.89	4.12	2.90	1.20	0.365
1995/1996	Fallow	6.25	2.89	5.69	0.76	0.082
	CGP	2.63	5.16	4.83	1.22	0.282
1996/1997	Fallow	6.57	1.85	4.82	1.30	0.129
	CGP [c)]	0.99	1.44	1.29	0.96	0.669
1997/1998	Fallow	4.90	4.07	5.44	1.32	0.777
	CGP	1.77	3.82	3.58	0.24	0.019
1998/1999	Fallow	4.60	2.06	3.20	0.72	0.137
	CGP	0.97	4.01	4.00	0.71	0.075
Total		40.30	42.20	48.00	8.89	0.071
Average fallow [d)]		5.79	3.10	4.90	0.57	<0.001
Average CGP [e)]		1.70	4.83	4.06	0.49	<0.001
Average $year^{-1}$ [f)]		7.24	8.42	9.27	1.47	0.142

Remarks = [a)] CGP = crop growing period. [b)] The plot was accidentally burnt, [c)] in this season all trees were pruned once only; in other seasons pruning frequency was adjusted to growth of the trees, resulting in one pruning event for for peltophorum and tree times for gliricidia hedgerows, [d)] excluding data for 1994/95 season, [e)] excluding data for the 1996/97 season, [f)] excluding data for the 1994/95 and 1996/97 seasons. SED: Standard Error of Difference of means.

Crop Yields

Crop yield of maize during the 1993/1994 to 1996/1997 cropping seasons is presented in Table 2. Average biomass and grain yields of maize of the second crop were lower than those of the first crop (Table 2) most likely due to the lower rainfall of 585 mm (38 days) to 876 mm (56 days) during the second crop as compared to the 869 mm (49 days of rain events) to 1299 mm (70 days) during the first crop. The use of hedgerow trees or increased fertiliser N application in the maize monocrop increased or maintained the biomass and grain yield in comparison with maize grown as a monoculture fertilized with 45 kg N ha^{-1}, except in the case of GG where biomass and yield were decreased significantly.

During the 1997/98 to 1998/99 cropping season, the average maize biomass and grain yield in GG was reduced by 38% (range from 33 to 44%) and 12% (range from 8 to 15%) respectively (Table 3). The reduction in maize biomass and yield was less for PG compared to GG. However, the biomass and maize yield in 1999 using the PP system were significantly higher than in the monoculture cropping system. The PP hedgerow cropping system produced 2.58 t ha^{-1} (2.42 to 2.74 t ha^{-1}) and 2.64 t ha^{-1} (2.12 to 3.17 t ha^{-1}) of maize biomass and grain yield respectively. Hedgerows maintained or significantly increased groundnut biomass and grain yield during the 1998 to 1999 cropping seasons in comparison to monoculture cropping systems.

Simulations

Simulation outputs fore crop biomass when compared with measured data biomass of crops showed a close fit for the monoculture cropping systems but underestimated crop performance in PP and GG (Figure 1.A). The simulated maize and groundnut grain yields in the 1997/98 crop growing period fitted the measured data well. However, in the 1998/1999 crop growing season only the simulated maize grain yield in the monocropping system fitted the measured data. For this period the maize yield in PP and GG were underestimated (Figure 1.B), whereas the groundnut grain yield was overestimated compared with the measured data for all cropping systems. The simulated data often indicated similar trends to the measured data with respect to the seasonal variability of biomass and grain yields for the PP and monocropping systems, but less for GG.

Table 2. Effect of hedgerow intercropping systems on yield of maize for 4 seasons (from 1993/1994 to 1996/1997 in hedgerow and monocrop (C) systems established in 1986).

Cropping systems	Average of biomass		Average of grain yield		Total of	
	1st crop	2nd crop	1st crop	2nd crop	Biomass residue	Grain yield
	t ha^{-1} (%*)					
PP+0 kg N ha^{-1}	2.05 (-14)	0.87 (-19)	1.77 (+18)	0.48 (-11)	8.74 (-15)	6.75 (+10)
GG+0 kg N ha^{-1}	1.60 (-33)	0.61 (-43)	1.19 (-21)	0.24 (-56)	6.63 (-36)	4.31 (-30)
PG+0 kg N ha^{-1}	1.69 (-29)	0.96 (-10)	1.66 (-11)	0.40 (-26)	7.93 (-23)	6.18 (+1)
C+45 kg N ha^{-1}	2.38 (0)	1.07 (0)	1.50 (0)	0.54 (0)	10.34 (0)	6.13 (0)
C+90 kg N ha^{-1}	2.21 (-7)	0.65 (-39)	2.13 (+42)	0.32 (-41)	8.59 (+17)	7.33 (+20)
SED	0.68	0.13	0.10	0.12	0.50	0.57
F_{pr}	<0.001	0.017	<0.001	0.124	<0.001	0.002

Remarks = *) Percentage of – decreased or + increased biomass and grain yields in comparison with maize monocropping + 45 kg N ha^{-1}. SED= Standard Error of Difference means

Table 3. Effect of hedgerow intercropping systems on crop yields for 4 seasons (from 1993/1994 to 1996/1997)

Cropping systems	Biomass		Grain yield		Average' 98&99	
	1998	1999	1998	1999	Biomass residue	Grain yield
	t ha^{-1} (%*)					
			Maize			
PP+90 kg N ha^{-1}	2.42 (+13)	2.74 (+31)	2.12 (+11)	3.17 (+60)	2.58 (+22)	2.64 (+36)
GG+90 kg N ha^{-1}	1.21 (-44)	1.41 (-33)	1.61 (-15)	1.82 (-8)	1.31 (-38)	1.72 (-12)
PG>P+90 kg N ha^{-1}	1.96 (-9)	1.79 (-15)	1.40 (-27)	2.17 (+10)	1.87 (-12)	1.78 (-8)
PG>G+90 kg N ha^{-1}	1.98 (-8)	1.77 (-16)	1.63 (-14)	2.02 (+3)	1.87 (-12)	1.83 (-6)
C+90 kg N ha^{-1}	2.15 (0)	2.10 (0)	1.91 (0)	1.97 (0)	2.12 (0)	1.94 (0)
SED between cropping systems	0.22	0.27	0.28	0.37	0.19	0.23
F_{pr}	<0.001	0.003	0.150	0.020	<0.001	0.059
SED between year of cropping system	0.12		0.16			
F_{pr}	0.89		0.002			
			Groundnut			
PP	5.04 (+38)	5.96 (+10)	1.24 (+3)	0.33 (+40)	5.50 (+68)	0.78 (+9)
GG	3.92 (+7)	4.31 (+49)	1.27 (+5)	0.51(+113)	4.11 (+25)	0.89 (+23)
PG>P	5.60 (+53)	5.09 (+75)	1.34 (+11)	0.30 (+28)	5.34 (+63)	0.82 (+24)
PG>G	5.50 (+50)	4.91(+69)	1.60 (+33)	0.28 (+19)	5.20 (+59)	0.94 (+31)
C	3.66 (0)	2.90 (0)	1.20 (0)	0.24 (0)	3.28 (0)	0.72 (0)
SED between cropping systems	0.52	0.50	0.13	0.08	0.34	0.09
F_{pr}	0.003	<0.001	0.046	0.029	<0.001	0.129
SED between year of cropping system	0.22		0.06			
F_{pr}	0.615		<0.001			

Remarks = *) Percentage of – decreased or + increased of biomass and grain yield in comparison with maize monocropping + 45 kg N ha^{-1}. SED= Standard Error of Difference of means.

The crop growth restriction indicator strongly suggested that light competition and water deficit rather than nitrogen restriction, was limiting groundnut performance (Figure 1.C, D and E). The water restriction for the 1998/99 crop growing period was more intense than for the 1997/98 crop growing period in all cropping systems. In contrast, maize performance appeared to be limited by nitrogen supply during grainfilling rather than by water shortage in monoculture, but in the hedgerow intercropping system light, water and nitrogen appeared to be the limiting factors.

Simulated peltophorum pruning yields were mostly close to measured yields in the 1997/98 crop growing period but were overestimated in the 1998/99 crop growing period (Figure 2). However, simulated gliricidia pruning yields were underestimated in the 1997/98 and overestimated in the 1998/99 crop growing period. The models indicated a responce due to drought during the dry season (period around 240 to 360 days).

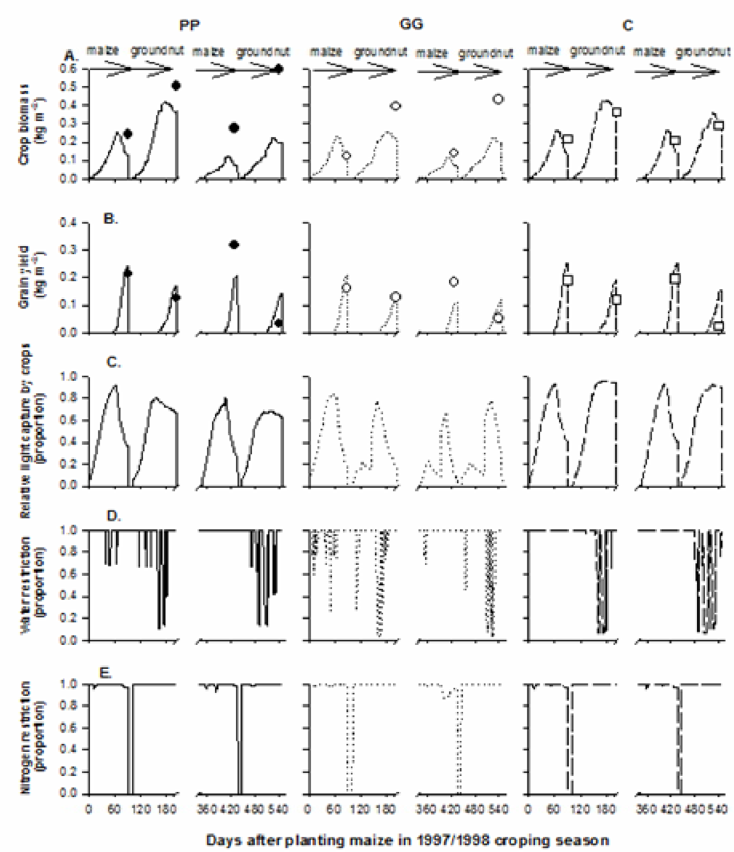

Figure 1. Simulated growth of maize and groundnut: (A) biomass (B) grain components (C) water (D) nitrogen restrictions with 90 kg N ha^{-1} input in each cropping season at all cropping systems on the growth of maize and groundnut in (—) PP, (…) GG and (---) monocropping systems for the 1997/98 to 1998/99 crop growing period. Symbols represent measured values.

Simulated cumulative biomass input into the soil system (1997/98 to 1998/99 crop growing periods) suggested that the PP system resulted in the highest input (2.92 kg m^{-2} of which 1.96 kg m^{-2} from peltophorum pruning, 0.05 kg m^{-2} from gliricidia litterfall and 0.91 kg m^{-2} from maize and groundnut biomass). Input from the GG system was similar (2.71 kg m^{-2} of which 1.5 kg m^{-2} from gliricidia pruning, 0.6 kg m^{-2} and 0.61 kg m^{-2} from maize and groundnut biomass) while monocropping gave the lowest input (0.97 kg m^{-2} from maize and groundnut biomass only) (Figure 3.A). Interestingly, carbon in SOM in GG increased by 71 g m^{-2} (2%) but decreased by 42 g m^{-2} (1%) and 216 g m^{-2} (7%) in the PP and monocropping systems respectively (Figure 3B) within 2 years. Nitrogen in SOM in GG increased by 2 g m^{-2} (1%), but decreased by 3.29 g m^{-2} (1%) and 18.19 g m^{-2} (6%) in the PP and monocropping systems respectively (Figure 3C).

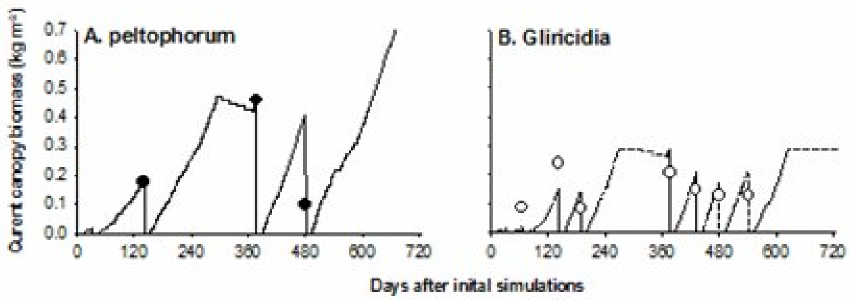

Figure 2. Simulated tree canopy biomass within (—) peltophorum in PP, and (…)gliricidia in GG hedgerow intercropping system for the 1997/98 to 1998/99 crop growing periods Symbols represent measured values were (•) peltophorum and (o) gliricidia trees.

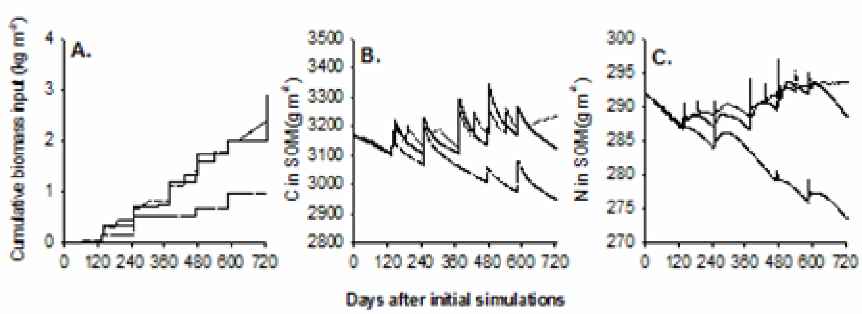

Figure 3. Comparison of simulated (A) cumulative biomass inputs (pruning + litterfall + crops), (B) cumulative C in SOM (soil organic matter) and (C) cumulative N in SOM at different cropping systems in (—) PP, (…) GG and (---) monocropping systems for the 1997/98 to 1998/99 crop growing period. Scenarios are presented with 90 kg N ha^{-1} input in each cropping season for all cropping systems.

DISCUSSION

The amount of pruning produced by the hedgerows from 8 to14 years after tree establishment was similar between the systems (7.22 to 8.88 t ha^{-1} $year^{-1}$). These measurements were similar to production in the same plots 2-4 years after hedgerow establishment (approximately 8 t ha^{-1} $year^{-1}$) as reported by Hairiah *et al.* (1992). These findings also agree with those reported by Young (1997) who found that hedgerow tree species in the humid tropics produce approximately 8 to 10 t ha^{-1} $year^{-1}$ of biomass. According to Young (1989) annual inputs of about 8.5 t ha^{-1} $year^{-1}$ of aboveground biomass are required in order to maintain a soil carbon content of 2 % (w/w) in a 11 cm top layer of soil with a bulk density of 1.4 g cm^{-3}. After 14 years, our hedgerow cropping systems still produced sufficient pruning to sustain soil organic matter. Our simulations support the conclusions that hedgerow cropping systems can sustain the soil organic matter (and N in SOM) but that monocropping cannot (Figure 3).

Interestingly, the peltophorum biomass yield in PP was greater during fallow periods but lower during thecrop growing periods when compared to the biomass yield of gliricidia in GG over the 6 years of measurement. This indicates that gliricidia trees are likely to compete more with the crop aboveground and belowground than peltophorum trees. The shape of gliricidia with no secondary branches may explain strong competition for light by gliricidia, as it develops stakes in an almost circular pattern around the hedge. In contrast, the canopy volume of peltophorum is remarkably small given its biomass, as it makes many secondary branches and forms a true hedge (Hairiah *et al*., 1992).

The belowground competitiveness of gliricidia tree hedges compared with peltophorum may be explained by root morphology of the two species. Rowe *et al.* (2002) demonstrated that gliricidia trees had a greater root length density in the top 20 cm of soil when compared to peltophorum trees. The greater root length density in the top 20 cm of gliricidia can potentially lead to higher competition for water and nutrientsThe simulation suggested that there was no water restriction during maize growth in the monocropping system, but that maize in the hedgerow intercropping systems with gliricidia experienced drought in dry spells during the growing season. Simulated transpiration of gliricidia was higher than peltophorum, due to a more exposed canopy. Competition for nitrogen was avoided in the case of gliricidia by BNF (additional inoputs to the system) and in the case of peltophroum by uptake from deeper layers (increased recycling). The higher tree fine root density in topsoil for gliricidia may have lead to higher competition for nutrient with low to intermediate mobility, such as P and K (Eissenstat, 1992). The WaNuLCAS model did link functions with a sufficiently detailed representation of above- and belowground architecture of gliricidia and peltophorum in the simulation of tree-soil-crop interactions. The positive net effect of peltohorum from the perspective of a maize crop is due to low competition (C) per unit fertility enhancement (F), rather than from superior fertility effects per se.

The above discussion is also supported by result of the total biomass and grain yield of maize during the 1993 to 1997 cropping seasons (Table 2). There were no significant differences between PP, PG, C45, and C90, but yield was significantly reduced in GG. Incorporation of the prunings of peltophorum in PP and PG into the soil produced maize grain yields equivalent to those resulting from the application of 45 kg ha^{-1} or even 90 kg ha^{-1} inorganic N in maize monoculture systems. Overall, the PP and PG intercropping systems showed a beneficial effect in long-term production and resulted in the largest yield increases and provides the best prospects in the long-term due to maintenance of the carbon and nitrogen stocks (Figure 3.B and C respectively).

Competition for N between the peltophorum hedge and the crop is apparent when yields for crops growing with peltophorum are compared to yield with and without fertiliser application (relatively higher yields of maize as presented in Table 3 compared to that in Table 2). To obtain higher yields, if the farmer wishes, an application of chemical fertiliser (45 kg N ha^{-1}) can still be worthwhile to peltophorum hedgerow intercropping system practices or in monocropping system. For the gliricidia hedgerow intercropping system, which had lower yields with or without chemical fertiliser than the other cropping systems, any application of fertiliser will not be economical.

Maize or groundnut yields mostly declined when the crop was nearer to the hedge.This was attributed to greater light and root competition.

Similar observation were made for caliandra and leucaena in the subhumid tropics (Mugendi *et al.*, 1999). However, they were considered to be mainly caused by greater root competition, because their hedges were maintained at a low height (50 cm) during the growing season.

The simulations gave similar trends with measured data on the effect of hedgerow intercropping on crop yield in PP and monocroping systems (Figure 1). However, the model suggested greater competition in gliricidia hedgerow cropping systems compared with measured data due to light and water competition. The other thing to note is that the groundnut in 1998/99 showed high biomass but low grain yield. These model results suggest that this was due to strong water stress during the grain filling period.

CONCLUSIONS

In conclusion, the results from this study indicate that a hedgerow intercropping system using peltophorum or alternating peltophorum and gliricidia hedges is advantageous for the acid soils of the humid environment at Lampung. However, inclusion of single species gliricidia hedges into the cropland adversely affected crop yield. Addition of 90 (45?) kg N ha^{-1} as a chemical fertiliser had a positive effect on crop yield in peltophorum hedgerow intercropping (low quality organic matter, hence slow release of mineral N from pruning material), but not for gliricidia (high quality organic matter, hence rapid release of mineral N from pruning material) and alternating peltophorum and gliricidia hedgerow cropping systems.

The WaNuLCAS simulation can help to understand the role of architecture and physiological processes involved in the effect of hedgerow intercropping on sustained crop yield in the long term. Our simulation suggested that soil organic matter (SOM) was declining in monocropping system but stable in hedgerows systems, which also kept nutrients in circulation that were lost by leaching in the maize monocrop. The basic principles of light, nutrient and water capture apply to any system where trees and crops share space with at least some overlap in time. The model can be used to extrapolate the lessons learnt from the relative success of peltophorum to other systems, once the basic architecture and temporal dynamics are described.

ACKNOWLEDGEMENTS

This publication is an output from a research project funded by the European Community (EC) and the Netherlands Government (TS2-0069-NL; 10/90/062) and the Department for International Development of the United Kingdom. However, the Department for International Development can accept no responsibility for any information provided or views expressed (R6523, Forestry Research Programme). Thanks are due to PT Bunga Mayang for allowing the use of land and other facilities.

REFERENCES

Cadisch, G., P. de Willigen, D. Suprayogo, D.C. Mobbs, M. van Noordwijk and E.C, Rowe. 2004. Catching and competing for mobile nutrients in soils. *In*: van Noordwijk, M., Cadisch, G. and Ong, C.K. (Eds.) Belowground Inter-actions in Tropical Agroecosystems, CAB International, Walling-ford (UK). p. 171-191.

Cannell, M.G.R., M. van Noordwijk and C.K. Ong. 1996. The central agroforestry hypothesis: the trees must acquire resources that the crop would not otherwise acquire. Agroforestry Systems 33: 1-5.

Eissenstat, D. M. 1992. Costs and benefits of constructing roots of small diameter. Journal of Plant Nutrition 15, p. 763-782.

Hairiah, K., M. Van Noordwijk, B. Santoso and Syekhfani. 1992. Biomass production and root distribution of eight trees and potential for hedgerow intercropping on an Ultisol in Southern Sumatra. Agrivita 15 (1) : 54-68.

Hulugalle, N. R. and J. N. Ndi. 1993. Effect of no-tillage and alley cropping on soil properties and crop yields in a Typic Kandiudult of southern Cameroon. Agroforestry Systems 22. p. 207-220.

ICRAF. 1995. “Annual report 1995,”. International Centre for Research in Agro-forestry, Nairobi, Kenya. pp.156.

Lal, R. 1989a. Agroforestry systems and soil surface management of a tropical alfisol: Effects on soil physical and mechanical properties. Agroforestry Systems 8: 197-215.

Lal, R. 1989b. Agroforestry systems and soil surface management of tropical Alfisol. V. Water infiltrability, transmissivity and water sorptivity. Agroforesty Systems 8: 217-238.

Mugendi, D. N., P.K.R.Nair, J.N. Mugwe, M. K. O'neill and P.L. Woomer. 1999. Alley cropping of maize with calliandra and leucaena in the subhumid highlands of Kenya. Part 1. Soil fertility changes and maize yield. Agroforestry Systems 46:. 39-50.

Oldeman, L. R., I. Las and S.N. Darwis. 1979. "An agroclimatic map of Sumatra". Contr. Centre Res. Inst. Agric., Bogor. pp.1.

Payne, R.W., P.W. Lane, A.E. Ainsley, K.E. Bicknell, P.G.N. Digby, J.C. Gower, S.A. Harding, P.K. Leech, H.R. Simpson, A.D. Todd, P.J. Verrier and R.P. White.1987. GENSTAT 5 Reference Manual. Oxford University Press, Oxford. pp.749.

Rao, M. R., P.K.R. Nair and C.K. Ong. 1998. Biophysical interactions in tropical agroforestry systems. Agroforestry Systems 38. p. 4-49.

Rowe, E. 1999. The safety-net role of tree roots in hedgerow intercropping systems. PhD thesis, University of London, Asford, Kent. pp.288.

Rowe, E.C., D. Suprayogo, K. Hairiah, M. van Noordwijk and G. Cadisch. 2002. Root Distribution of Maize, Gliricidia and Peltophorum in Hedgerow Inter-cropping Systems. Agrivita 23 (2): 102-109.

Sanchez, P. A. 1995*. Science in agroforestry. Agroforestry systems* 30, p 5-55.

Suprayogo, D. 2000. Testing the "safety-net" hypothesis in hedgerow intercropping: water balance and mineral N leaching in the humid tropics. PhD thesis, University of London. p. 70-105.

Van Der Heide, J., S. Setijono, M.S. Syekhfani, E.N. Flach, K. Hairiah, S. Ismunandar, S.M. Sitompul and M. van Noordwijk. 1992. Can low external input cropping systems on acid upland soils in the humid tropics be sustainable ?: Bacgrounds of the UNIBRAW/IB Nitrogen management project in Bunga Mayang (Sungai Selatan, Kota bumi, N. Lampung, S. Sumatra, Indonesia). Agrivita 15(1) : 1-9.

van Noordwijk, M, Widianto, M. Heinen and K. Hairiah. 1991. Old tree root channels in acid soils in the humid tropics: Important for crop root penetration, water inflitration and nitrogen management. *In* "Plant-soil interactions at low pH" (R. J. Wrighgt, V.C. Baligar and R.P. Murrmann, eds.), Kluwer Academic Publishers, The Netherlands. p.423-430.

van Noordwijk, M, S.M. Sitompul, K. Hairiah, E. Listyarini and M.S. Syekhfani. 1995. Nitrogen supply from rotational or spatially zoned inclusion of Leguminosae for sustainable maize production on an acid soil in Indonesia. *In* "Plant-soil interactions at low pH" (R. A. Date, N. J. Grundon, G. E. Rayment and M. E. Probert, eds.), Kluwer, Dordrecht, The Netherlands. p. 779-784.

van Noordwijk, M. and B. Lusiana. 1999. WaNuLCAS 2.0.: Backgrounds of a models of water, nutrient and light capture in agroforetsry systems.. International Centre for Research in Agroforestry (ICRAF), ICRAF-S.E. Asia, Bogor. pp.186.

van Noordwijk, M. and G. Cadisch. 2002. Access and excess problems in plant nutrition. Plant and Soil 247: 25-39

Von Uexkull, H. R. 1986. "Efficient fertilizer use in acid upland soils of the humid tropics," FAO, Rome. 59 pp.

Young, A. 1989. "Agroforestry for soil con-servation," CAB International, Walling-ford, England. pp.276.

Young, A. 1997. "Agroforestry for Soil Manage-ment (2nd edition)," CAB International, Wallingford, UK. pp.320.