SWEET POTATO PRODUCTION IN HEDGEROW INTERCROPPING SYSTEMS IN THE LOWLANDS OF PAPUA NEW GUINEA.

Bas Louman[1] and Alfred E. Hartemink[2]

ABSTRACT

In an experiment in the Morobe Province of Papua New Guinea, sweet potato (Ipomoea batatas) *was grown between* Leucaena diversifolia *and* Acacia auriculiformis *hedgerows (1650 trees ha^{-1}), and as a sole crop. The experiment was conducted at three locations on Entisols and Inceptisols at altitudes below 550 m a.s.l. Sweet potato yields, above ground biomass of the trees, and nutrient contents of the leaf mulch were measured from 1992 to 1994. The hedgerows were coppiced annually. There were no significant differences in sweet potato yields between the intercropped hedgerows and when grown as a sole crop. Average marketable tuber yields were very low and varied from 2.1 to 6.6 t ha^{-1} yr^{-1} (CV%: 27-51%). Biomass (i.e. wood and mulch) production of* Leucaena *and* Acacia *was also low but varied widely between years.* Leucaena *produced significantly more biomass (7.6 t ha^{-1}) than* Acacia *(1.8 t ha^{-1}) only in 1994. The nitrogen concentration of the* Leucaena *leaves (mean 29.5 g kg^{-1}) was higher than of* Acacia *(mean 21.1 g kg^{-1}) but phosphorus concentrations were similar. Potassium and sulphur concentrations were higher in* Leucaena *than in* Acacia *in 1993 and 1994. Due to higher biomass production and higher nutrient concentrations, there were more nutrients returned to the soil with* Leucaena *than with* Acacia *mulch. After three seasons of sweet potato cropping, no statistical differences in soil chemical properties were found. It was concluded that annually coppiced* Leucaena *and* Acacia *hedgerows is attractive for subsistence farmers in areas where wood or fodder is scarce since it is not affecting sweet potato yields.*

Key words: *Sweet potato, hedgerow intercropping,* Leucaena diversifolia, Acacia auriculiformis, *soil fertility, Papua New Guinea.*

INTRODUCTION

Papua New Guinea has a low population density (8.9 km^{-2}) and about 75 to 80% of the land is covered with natural forests (FAO 1995; McAlpine and Quigley 1995). Forests and people, however, are not evenly distributed over the country. Several areas are densely populated with only little or degraded forests remaining by which the availability of firewood is reduced (Louman 1991). In such areas food production is affected and has resulted for example in the replacement of taro (*Colocasia esculenta*) by sweet potato (*Ipomoea batatas*) due to its lower demand on the soil and the greater ease of cultivation (Barrau 1958). Sweet potato is the main staple crop for the majority of the people in Papua New Guinea (Allen *et al.* 1995). Yields are very variable and much depends on the environmental conditions (e.g. altitude, soils, climate), varieties and the system of cultivation (e.g. mounds, plant density). Bourke (1985) listed yield records of subsistence sweet potato gardens in Papua New Guinea and 30 to 50 t ha^{-1} (fresh weight) are obtained in some areas whereas in others yield levels hardly exceed 5 t ha^{-1}.

Yields can be substantially increased by the selection of cultivars (Levett and Osi'lis 1990) and by improved husbandry practices. Bourke (1985) reviewed the literature on fertilizer trials conducted in Papua New Guinea and noted that consistent yield responses to organic fertilizers (i.e. manure, coffee pulp, poultry litter) and inconsistent responses to inorganic fertilizers. For many farmers

[1] Department of Forestry, University of Technology, PMB, Lae, Papua New Guinea
(Current address: CATIE, CATIE 7170, Turrialba, Costa Rica)
[2] Department of Agriculture, University of Technology, PMB, Lae, Papua New Guinea
EMAIL: aharteminK@ag.unitech.ac.pg (Corresponding author)

organic fertilizers are not available, and inorganic fertilizers are too expensive or crop response and profitability is poor. One possible way to overcome the lack of organic fertilizers is to grow crops on the farm where biomass can be added to the soil to improve its fertility status. A system which has received considerable attention during the past decade is the hedgerow intercropping or alley cropping system by which food and tree crops are mixed in spatial and temporal arrangements (Sanchez 1995).

Literature on the use of sweet potato in hedgerow intercropping systems is limited and most trials were conducted with maize. Sweet potato is perhaps not a very suitable crop grown between rows of trees because it is sensitive to shading which seriously reduce yields (e.g. Martin 1985; Roberts-Nkrumah *et al.* 1986). Planting trees, which are regularly coppiced in sweet potato gardens, could have benefits outweighing the possible yield loss through shading as the trees may produce fodder or fuelwood which is important in highly populated areas. We therefore conducted an experiment that examined sweet potato yields of a sole crop, and when intercropped between annually coppiced hedgerows of *Acacia auriculiformis* and *Leucaena diversifolia*. The research took place on-farm in the lowlands of Papua New Guinea.

MATERIALS AND METHODS

The sites

The experiment was carried out on three sites: Unitech (University of Technology), Hobu, and Musom in the Morobe Province of Papua New Guinea. Unitech (6°41'S, 146°98'E) is located at an alluvial plain 8 km N of Lae at an altitude of 65 m a.s.l. The experimental site had a slope of 1.5%. Mean annual rainfall is 4420 mm and the rain is evenly distributed throughout the year. Average daily temperatures are 26.3°C with a daily minimum of 22.9°C and a maximum of 29.7°C. Annual evaporation (US Class A pan) is 2140 mm, and rainfall exceeds evaporation in each month (McAlpine *et al.* 1975).

Hobu village (6°34'S, 147°02'E) is located in the Saruwaged mountain range at an altitude of about 440 m a.s.l. The plots at Hobu were located on a slope of 70%. There are no climatic data available for the site but annual rainfall is probably lower than at Unitech and between 1800 and 2500 mm (Ford 1974).

Musom village (6°31'S, 146°59'E) is also situated in the Saruwaged range, at an altitude of 550 m a.s.l. At Musom, the experimental plots were lo-

Table 1. **Soil analytical data of selected horizons at the experimental site[1].**

Site	Unitech		Hobu		Musom	
sampling depth (m)	0-0.23	0.42-0.57	0-0.10	0.40-0.70	0-0.26	0.42-0.67
pH H_2O (1.5)	5.9	6.4	6.2	5.6	6.0	5.8
Organic C (g kg^{-1})	24	5	28	8	29	10
Total N (g kg^{-1})	2.0	0.4	2.4	0.8	2.6	0.9
Available P (Olsen) (mg kg-1)	11.5	2.5	5.6	0.3	4.8	4.3
Exchangeable Ca (mmol$_c$ kg^{-1})	232	242	267	221	276	300
Exchangeable Mg (mmol$_c$ kg^{-1})	45	48	92	107	52	85
Exchangeable K (mmol$_c$ kg^{-1})	6.5	1.1	7.0	1.7	16.5	7.2
CEC (mmol$_c$ kg^{-1})	126	35	289	194	434	476
Bulk density (kg dm^3)	1.10	1.11	0.90	n.d.	0.86	n.d.

[1] Data are of samples taken in soil pits in March 1996.
n.d. not determined

cated on a slope of 20%. Climate is probably similar to that of the Hobu site although average temperatures are slightly lower.

Soils

Soils at the Unitech site are derived from alluvial deposits consisting of sedimentary and igneous rocks originating from the Saruwaged mountain range. The soils at Unitech are classified as Entisols or Typic Tropofluvents (Soil Taxonomy). At Hobu and Musom soils have developed in a mixture of colluvial poorly sorted material deposited on igneous rocks. At both sites, the soils were classified as Inceptisols or Typic Eutropepts. Some analytical data of the soils at the three sites are listed in Table 1. Soils at the experimental sites had fair fertility levels with moderately acid soil reactions. Levels of available phosphorus were moderate in the Unitech soils but low at Hobu and Musom.

Experimental Design

Prior to the establishment of the experiment, the block at Unitech was covered with *Imperata* grass and trees, whereas at the Hobu site grass and other weeds dominated the plots. Secondary forest with some coffee trees was dominant at the site in Musom.

The experiment was set up as a randomized complete block design with three replicates and three treatments: (i) sweet potato monocropping, (ii) sweet potato with *Acacia auriculiformis* hedges, and (iii) sweet potato with *Leucaena diversifolia* hedges. The sites at Unitech, Hobu and Musom were treated as a block and each block had three plots of 4.5 m by 12 m. Measurements took place in 1992, 1993 and 1994.

The hedges were planted in June 1991 at 4 m intervals with 1.5 m between the trees (9 trees per plot, 1650 trees ha^{-1}). A first sweet potato crop was cultivated in 1991, but no data were collected. In June 1992, sweet potato cuttings of five local cultivars (kuk, pipi, watu, sakat, and kwimbu) were planted. Two cuttings were planted in mounds with a diameter of 0.75 m and a height of about 0.20 m. Distance between the mounds was 1 m, resulting in 3 rows of sweet potato between the hedges (7500 sweet potato plants ha^{-1}). The sweet potato monocropping plots had a plant density of 10,000 plants ha^{-1}. Weeds were manually uprooted every month but the weeds were not removed from the field. After the harvest of the sweet potato, the plots were left fallow until the next planting season. All crop residues were returned to the plots.

Biomass Sampling

In November and December of each year, the sweet potato was harvested. The fresh weight of sweet potato tubers and vines was weighed in the field and in each plot, five samples of four plants were taken. One tuber of each sample was oven dried at 70°C for the first, and at 105°C for the second 24 h. The fourth and fifth full leaf from the base of the vine were sampled and for each sample 24 leaves were taken for analysis. The leaves were cleaned by dipping them in de-ionized water and dried with tissue before ovendrying at 70°C. After 24 h in the oven, 5 to 6 g of the sample was taken and sent to the National Analysis Laboratory in Lae for analysis of the N,P,K and S content. The remaining leaves were dried for another 24 hours at 105°C for dry weight determination.

Trees were coppiced at 0.4 m above ground level in June of each year and the biomass was determined. The biomass was divided into three categories: (i) leaves and petioles, (ii) branches with a diameter less than 0.02 m, and (iii) branches and stems with a diameter over 0.02 m (firewood). Total fresh weight per plot (9 trees) was determined in the field for each component. Samples of the leaves were taken after thorough mixing and cleaned with a tissue. The samples were ovendried at 70°C and after 24h 5 to 6 g were taken for nutrient analysis. The small branches were cut into 0.1 m lengths, mixed, and a 0.5 kg sample was taken and ovendried. Firewood was cut into 1 m lengths and the 0.1 m base of each 1 m piece was ovendried for dry matter determination.

Soil Sampling and Analysis

At the experimental sites, soil pits were dug in March 1996 and soil samples were taken of each horizon. In addition, the *Leucaena*, *Acacia* and sole sweet potato plot were sampled at Hobu and Musom. In each plot, nine samples of 0-0.15 m depth were taken using an Edelman auger. These were thoroughly mixed whereafter a subsample was taken. All samples were airdried, ground and passed through a 2 mm sieve. Samples were analyzed at the National Analysis Chemistry Laboratory in Port

Moresby. The following methods were used: pH H_2O in 1:5 suspension of soil and water; organic carbon by $K_2Cr_2O_7$ and H_2SO_4 oxidation (Walkley and Black); total N by Kjeldahl; available P by $NaHCO_3$ extraction (Olsen); exchangeable cations Ca, Mg, K, Na and CEC percolation by 1 M NH_4OAc followed by spectrophotometry (K, Na), AAS (Ca, Mg) and titration (CEC).

Statistical analysis

Data on fresh weight of tubers, dry weight of above ground tree biomass and nutrient content of tree leaves were analysed statistically using Minitab (version 8). ANOVA showed no significant differences between the years and the data were subsequently analysed separately for each year. Coefficients of Variance (CV%) are reported for sweet potato yields, whereas student's *t*-tests were used to compare the biomass production of trees and the nutrient content of the leaves.

Soil analytical data after three cropping seasons were analyzed by ANOVA using Statistix4.1 software. Standard error for the difference in means is reported.

RESULTS

Biomass production

Statistical analysis revealed no significant differences in sweet potato yields between treatments and years. The *Leucaena* treatment yielded 2.1 to 4.9 t tubers ha^{-1} between 1992 and 1994, whereas yields in the sole sweet potato plots were varying between 2.9 to 6.6 t ha^{-1} (Table 2). Variation was large between the years and within the treatments. It was lowest in 1994 (CV 27%) and in the *Acacia*

Table 2. **Sweet potato yields of intercropped and sole sweet potato plots from 1992 to 1994 (t ha^{-1} fresh weight).**

	1992	1993	1994	CV%
Leucaena	2.1	4.9	3.1	46
Acacia	3.5	4.1	2.4	39
sole sweet potato	2.9	6.6	3.2	51
CV%	47	46	27	

Table 3. **Wood and mulch production of *Leucaena* and *Acacia* from 1992 to 1994 (t ha^{-1} dry weight).**

	1992			1993			1994		
	wood	mulch	total	wood	mulch	total	wood	mulch	total
Leucaena	1.0	1.1	2.1	0.8	1.3	2.1	4.9	2.7	7.6
Acacia	0.3	0.8	1.1	0	0.1	0.1	0.5	1.3	1.8
Difference	n.s.	n.s.	n.s.	n.s.	P<0.05	n.s.	P<0.05	n.s.	P<0.05

n.s. not significant

Table 4. **Nutrient concentrations in *Leucaena* and *Acacia* leafs from 1992 to 1994 (mg kg^{-1}).**

Nutrient	Tree	Year 1992	1993	1994
Nitrogen	*Leucaena*	32.2	33.1	23.3
	Acacia	23.3	21.9	18.2
	Difference	P<0.05	P<0.05	P<0.05
Phosphorus	*Leucaena*	2.9	3.5	4.4
	Acacia	3.0	3.1	4.6
	Difference	n.s.	n.s.	n.s.
Potassium	*Leucaena*	13.3	14.4	13.9
	Acacia	10.3	10.4	11.8
	Difference	n.s.	P<0.05	n.s.
Sulphur	*Leucaena*	2.2	1.5	2.2
	Acacia	1.4	0.9	1.5
	Difference	n.s.	P<0.05	P<0.05

n.s. not significant

Table 5. **Nutrient in the tree leaf mulch from 1992 to 1994 (kg ha^{-1}).**

Nutrient	Tree	Year 1992	1993	1994	Total
Nitrogen	*Leucaena*	15	20	38	73
	Acacia	10	1	10	21
	Difference	n.s.	n.s.	P<0.05	P<0.05
Phosphorus	*Leucaena*	1	2	7	10
	Acacia	1	<0.5	2	3
	Difference	n.s.	n.s.	P<0.05	P<0.05
Potassium	*Leucaena*	6	9	23	38
	Acacia	4	1	6	11
	Difference	n.s.	n.s.	P<0.05	P<0.05
Sulphur	*Leucaena*	1	1	4	6
	Acacia	<0.5	<0.5	1	2
	Difference	n.s.	P<0.05	P<0.05	P<0.05

n.s. not significant

treatment (CV 39%).

Large variation was also found in the wood and mulch production of *Leucaena* and *Acacia*. In 1994, *Leucaena* produced significantly more wood than in 1992 or 1993, and it produced more wood than *Acacia* which production was on average less than 0.5 t ha^{-1} yr^{-1} (Table 3).

Mulch production did not differ significantly between *Acacia* and *Leucaena* except in 1993 when Acacia (0.1 t ha^{-1}) produced significantly lower than *Leucaena* (1.3 t ha^{-1}). *Leucaena* produced significantly more biomass than *Acacia* in 1994 only.

Nutrients

Nitrogen concentrations in *Leucaena* leaves were consistently higher than those in *Acacia* leaves (Table 4). In 1994, nitrogen concentrations were lower than in 1993 or 1992 for both *Leucaena* and *Acacia*. Phosphorus concentrations increased significantly in the *Leucaena* leaves between 1992 and 1994. No statistical difference was observed in the phosphorus concentrations between *Leucaena* and *Acacia* leaves. Potassium concentrations of *Leucaena* an *Acacia* did not change between 1992 and 1994. Sulphur concentrations showed a significant decline in 1993 in both tree species. Sulphur concentrations of *Leucaena* leaves were higher than of *Acacia* in both 1993 and 1994.

Due to the higher tree leaf mulch production and the higher nitrogen concentration, there was more nitrogen returned with the mulch of the *Leucaena* than with the *Acacia* in 1994 (Table 5). Overall, significant more nutrients were returned to the soil by the *Leucaena* than by the Acacia mulch. It also seems that total nutrients returned with the *Leucaena* mulch increased over the years but such trend was not found in the *Acacia*. After three seasons of sweet potato cropping there were no significant differences between the soils under *Leucaena*, *Acacia* or sole sweet potato (Table 6).

DISCUSSION

Sweet potato yields ranged from 2.1 to 6.6 t ha^{-1} which are very low but not exceptional low yields for smallholders in the lowlands of Papua New Guinea (Bourke 1985). Sayok and Hartemink (1998 this issue) also found low yield levels of sweet potato in the Hobu area of the Morobe Province. The reasons for the low yield levels are hitherto not fully understood but could be due to the varieties grown.

We expected tuber yields in sole sweet potato plots to be higher due to the absence of shading and the

Table 6. **Topsoil (0-0.15 m) chemical properties after 3 seasons of intercropped and sole sweet potato cultivation[1].**

	Leucaena	*Acacia*	sole sweet potato	SED[2]
pH H_2O (1:5)	5.9	5.9	6.1	0.13
Organic C (g kg^{-1})	37	33	32	8
Total N (g kg^{-1})	3.4	3.0	2.9	0.6
Available P (Olsen) (mg kg^{-1})	4.4	5.3	7.7	4.0
Exchangeable Ca ($mmol_c$ kg^{-1})	264	274	304	40
Exchangeable Mg ($mmol_c$ kg^{-1})	52	72	76	26
Exchangeable K ($mmol_c$ kg^{-1})	13	16	12	8
CEC ($mmol_c$ kg^{-1})	412	390	454	58
Base saturation (%)	81	93	86	6

[1] Data reported are means of soil samples taken at Hobu and Musom in March 1996

[2] Standard error of the difference in means (5 *df*)

25% higher plant density. This was reported from intercropping systems with sweet potato in Rwanda (Balasubramanian and Sekayange 1991) and Sierra Leone (Karim *et al.* 1991). However, in our experiment we found no significant yield differences between sole and intercropped sweet potato. The absence of differences is possibly due to the low yields that apparently cause a high degree of variation (CV: 39 to 51%). There were also no significant yield trends during the years which again may be due to the low yield level with the high associated variability (CV: 27 to 47%).

The amount of mulch (small branches and leaves) produced during 1992 and 1993 by the *Leucaena diversifolia* trees was 1.1 and 1.3 t ha^{-1} respectively. Such mulch production is very low when compared to *L. leucocephala* in West Africa (e.g. Kang *et al.* 1985; Palada *et al.* 1992; Shannon and Vogel 1994) but similar to *L. leucocephala* mulch production in East Africa (Jama *et al.* 1988; Macklin *et al.* 1989). In the New Britain Province of Papua New Guinea *L. diversifolia* produced about 2.3 t dry weight ha^{-1} yr^{-1} (Brook 1992). The low mulch production of the *Leucaena* trees in our experiments may be due to the low plant density (1650 trees ha^{-1}) and psyllid (*Heteropsylla cubana*) damage which was observed during the first three months after coppicing.

Mulch production of Acacia was similar to *Leucaena* except during 1993 because of a dry spell that occurred after coppicing. It is generally found that *Acacia auriculiformis* coppices poorly under dry conditions and preferably coppicing should take place during the wet season (Turnbull 1986). We observed that Acacia trees which survived coppicing, had usually one or more branches remaining below 40 cm. Ryan and Bell (1989) and Turnbull (1986) also found that regrowth of *A. auriculiformis* is better when one living branch is left after coppicing.

Nitrogen concentrations in the *Leucaena* and *Acacia* leaves were similar to those found by other researchers (e.g. Brook 1992; Xu *et al.* 1992; Young, 1989), but lower than the 43 to 44 g kg^{-1} found by Palada *et al.* (1992). Leaf phosphorus concentrations were higher than those found by Brook (1992), whereas potassium concentrations were lower than reported by Brook (1992) and Young (1989).

Significantly more nutrients were returned with the *Leucaena* mulch than with the *Acacia* mulch in 1994. Absolute quantities are, however, low. The low sweet potato yields under *Leucaena* indicate that the nutrient additions with the mulch did not have a significant influence on the yield. It was also found that after three seasons there were no differences in soil fertility between sole sweet potato and the intercropped plots. Apparently, at the current low levels of production, the limited nutrient inputs with mulch and nutrient outputs by the tubers do not have a significant effect on soil chemical properties.

CONCLUSION

At the low external input level in the lowlands of the Morobe Province, annually coppiced hedgerows of *Leucaena diversifolia* or *Acacia auriculiformis* do not affect sweet potato yields. The hedgerows produce fodder and fuelwood, which is beneficial to the farmers.

ACKNOWLEDGMENTS

The authors wish to acknowledge the support of the Research Committee of the University of Technology in Lae and the kind assistance of the farmers' community at Hobu and Musom.

REFERENCES

ALLEN, B.J., BOURKE, R.M. and **HIDE, R.L.** (1995). The sustainability of Papua New Guinea agricultural systems: the conceptual background. *Global Environmental Change* 5: 297-312.

BALASUBRAMANIAN, V. and **SEKAYANGE, L.** (1991) Effects of tree legumes in hedgerows on soil fertility changes and crop performance in the semi-arid highlands of Rwanda. *Biological Agriculture and Horticulture* 8: 17-32.

BARRAU, J. (1958) *Subsistence agriculture in Melanesia*. Bernice P. Bishop Museum Bulletin 219. Bishop Museum Press, Honolulu.

BOURKE, R.M. (1985) Sweet potato (*Ipomoea batatas*) production and research in Papua New Guinea. *Papua New Guinea Journal of Agriculture, Forestry and Fisheries* 33: 89-108

BROOK, R. (1992) Early results from an alley cropping experiment in the humid lowlands of Papua New Guinea. *Nitrogen Fixing Tree Research Reports* 10: 73-76

FAO (1995). *Forest resource assessment 1990, global synthesis.* FAO, Rome.

FORD, E. (1974) Climate. In: Ford E (ed) Papua New Guinea resource atlas, pp 8-9. Jacaranda Press, Milton.

JAMA, B., GETAHUN, A., NGUGI, D. and **MACKLIN, B.** (1988) *Leucaena alley cropping for the Kenyan coast.* In: Prinsley RT and Swift MJ (eds) Amelioration of soil by trees, pp 155-172. Commonwealth Secretariat, London

KANG, B.T., GRIMME, H. and LAWSON, T.L. (1985) Alley cropping sequentially cropped maize and cowpea with Leucaena on a sandy soil in Southern Nigeria. *Plant and Soil* 85: 267-277

KARIM, A.B., SAVILL, P.S. and **RHODES, E.R.** (1991) The effect of young *Leucaena leucocepahala* (Lam) De Wit hedges on the growth and yield of maize, sweet potato and cowpea in an agroforestry system in Sierra Leone. *Agroforestry Systems* 16: 203-211.

LEVETT, M.P. and **OSI'LIS, P.** (1990) *Preliminary agronomic evaluation of 383 sweet potato (*Ipomoea batatas *(L.) Lam.) accessions grown on a clayloam soil under wet tropical lowland conditions at Laloki, Central Province.* Technical report 90/4. Department of Agriculture and Livestock, Konedobu.

LOUMAN B. (1991) The possible contribution of social forestry to forest development in Papua New Guinea. *Klinkii* 4: 24-39

MACKLIN, B., JAMA, B., KEDIR, R., and **GETAHUM, A.** (1989) Results of alley cropping experiments with *Leucaena leucocephala* and *Zea maize* at the Kenya coast. *Leucaena Research Reports* 9: 61-64

MARTIN, F.W. (1985) Differences among sweet potatoes in response to shading. *Tropical Agriculture* 62: 161-165

McALPINE, J.C., KEIG, G., and **SHORT, K.** (1975) *Climatic tables of Papua New Guinea.* CSIRO, Canberra.

McALPINE, J.C. and **QUIGLEY, J.** (1995) Papua New Guinea natural resources, land use and population û Summary statistics from PNGRIS. PNGRIS Report no. 7, CSIRO, Brisbane.

PALADA, M.C., KANG, B.T. and **CLAASEN, S.L.** (1992) Effect of alley cropping with *Leucaena leucocephala* and fertilizer application on yield of vegetable crops. *Agroforestry Systems* 19: 139-147

ROBERTS-NKRUMAH, L., WILSON, L.A., and **FERGUSON, T.U.** (1986) Response of four sweet potato cultivars to levels of shade: 2. Tuberization. *Tropical Agriculture* 63: 265-270

RYAN, P.A. and **BELL, R.E.** (1989) *Growth, coppicing and flowering of Australian tree species in trials in southeast Queensland, Australia.* In: Boland DJ (ed) Trees for the tropics: growing Australian multi purpose trees and shrubs in developing countries, pp 49-68. ACIAR Monograph 10. ACIAR, Canberra.

SAYOK, A. and **HARTEMINK, A.E.** (1998) Erosion and soil fertility changes under leucaena intercropped with sweet potato in the lowlands of Papua New Guinea. *Papua New Guinea Journal of Agriculture, Forestry and Fisheries* 41: 85-90 (This issue)

SANCHEZ, P.A. (1995). Science in agroforestry . *Agroforestry system* 30: 5-55.

SHANNON, D.A. and **VOGEL, W.O.** (1994) The effects of alley cropping and fertilizer application on continuously cropped maize. *Tropical Agriculture* 71: 163-169

TURNBULL, J.W. (1986) *Multipurpose Australian trees and shrubs, lesser-known species for fuelwood and agroforestry.* ACIAR Monograph 1. ACIAR, Canberra

XU, Z.H., SAFFIGNA, P.G., MYERS, R.J.K., and **CHAPMAN, A.L.** (1992) Nitrogen fertilizer in *Leucaena* alley cropping I: Maize response to nitrogen fertilizer and fate of fertilizer-15N. *Fertilizer Research* 33: 219-227

YOUN, A. (1989) *Agroforestry for soil conservation.* CAB International, Wallingford.