EROSION AND SOIL FERTILITY CHANGES UNDER LEUCAENA INTERCROPPED WITH SWEET POTATO IN THE LOWLANDS OF PAPUA NEW GUINEA

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ABSTRACT

Surface runoff, erosion and changes in soil fertility were measured under Leucaena leucocephala *intercropped with sweet potato and compared to sole* Leucaena leucocephala *cropping. The study was conducted on-farm in the humid lowlands of Papua New Guinea for two years (1992-1993 and 1993-1994). The soil at the site was derived from intrusive igneous rocks (Inceptisol) and had a slope of 58%. In the intercropped plots (150 m² each) during the two years of observation, surface runoff was 817 and 1003 mm yr⁻¹, or 37% and 55% of the total rainfall. Erosion was low and on average 3.9 and 2.9 t soil ha⁻¹ yr⁻¹. Under sole leucaena, surface runoff was 537 and 668 mm yr⁻¹ and erosion was 3.5 and 2.2 t soil ha⁻¹ yr⁻¹. Linear regression showed that both monthly rainfall and surface runoff, and surface runoff and erosion were well correlated (r^2 >0.6) for intercropped and sole leucaena. Soil fertility declined under intercropped and sole leucaena but there were no major differences. There were also no statistical differences in the height of the leucaena. Sweet potato yields declined from 4.2 t fresh weight ha⁻¹ at the first harvest to 0.2 t ha⁻¹ after 23 months in the intercropped plots. The study has shown that intercropping leucaena with sweet potato during the first two years does not significantly increase erosion or affect the soil fertility as compared to sole leucaena.*

Keywords: *surface runoff; erosion; soil fertility changes; sweet potato; intercropping;* Leucaena leucocephala.

INTRODUCTION

About 75% of Papua New Guinea is covered with forest of which more than half is on steepland (McAlpine and Quigley 1995). Deforestation by logging, mining, agricultural projects and shifting cultivation is proceeding rapidly and annually about 113,000 ha of forest are cleared (FAO 1990). Much of the forest clearings is required for the expansion of agricultural land. Reforestation, required to avoid irreversible land degradation, occurs at a much slower pace and recent estimates are 1,500 ha yr⁻¹ (FAO 1990).

For smallscale farmers who are to a large extent responsible for the deforestation, there are little incentives to plant trees as it reduces their cropping area and they may have to wait for a long time before an economic return can be expected. A partial solution to this problem is the planting of food or cash crops in between rows of trees during the first years which may give some return to the investment of planting trees. This has been practised in many parts of the tropics for a long time and it is usually referred to as the taungya system (Nair 1993). A second incentive is that trees such as *Leucaena leucocephala* can have multiple use. They supply animal feed and wood for timber, pulp or fuel and the mulch can be used for soil improvement. Furthermore *Leucaena* planted on the contour may assist in soil conservation. Planting sweet potato, which is the major starch crop in the lowlands of Papua New Guinea (Allen *et al.* 1995), between rows of *Leucaena* is therefore an attractive land-use system as it produces food and products of the tree. The planting of *Leucaena* trees

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may save further clearing of the forest and reduce land degradation by erosion and the loss of nutrients (Sanchez 1995).

For Papua New Guinea, little is known on the effect of sweet potato and *Leucaena* on soil erosion and the chemical fertility. Therefore an experiment was started in May 1992 with the following objectives: (i) to quantify runoff and erosion in intercropped and sole *Leucaena* plots, (ii) to determine changes in soil chemical properties, (iii) to assess sweet potato yields and the growth of *Leucaena*. The experiment was conducted in the lowlands near Lae in an area were selective logging is followed by the encroachment of small scale farmers. The experiment lasted for two years during which the *Leucaena* trees were not pruned.

MATERIALS AND METHODS

Study area

The study was conducted on-farm near Hobu Community School (6°34'S, 147°02'E) approximately 20 km northeast of Lae at the footslopes of the Saruwaged range. Altitude of the experimental site was 440 m a.s.l. which is considered as lowlands in the agro-climatic classification of Papua New Guinea (Gurnah 1992). Detailed climatic data are not available for the study area. The experiment was situated in an area with high annual rainfall and mean temperatures over 25°C with only slight variations during the year. Annual evaporation (US Class A pan) is about 1500 to 2000 mm (McAlpine *et al.* 1982). The climate is classified as Af (Köppen), a tropical rainy climate with the driest month having over 60 mm of rain.

Slope at the experimental site is 58%. The soils are derived from a mixture of igneous rocks, and are classified as a Typic Eutropepts (Soil Survey Staff 1994) or Eutric Cambisol (FAO-Unesco 1988). Some chemical and physical properties of the soils are presented in Table 1.

The soils have a moderate to slightly acid soil reaction and fair levels of total N and exchangeable cations. Available P levels are low. Effective rooting depth is over 1.2 m. Landslides occasionally occur in the area and are triggered off by earthquake activity after periods of heavy rain (Bleeker 1983).

The natural vegetation in the area is similar to the lowlands and submontane forest in the region. The dominant canopy is formed by *Pometia* sp., *Syzygium* sp. and *Eleocarpus* sp. whereas *Canarium* sp., *Neonauclea* sp., *Dracontemelon* sp., *Dysoxylum* sp., and *Chisocheton* sp. form the co-dominant canopies. (J. Simaga pers. comm.). Areas which have been frequently burned are predominantly under grasslands consisting of *Themeda* sp., *Imperata* sp. and *Saccharum* sp.

Experimental set-up

The experimental site was an abandoned garden previously planted with a mixture of sugarcane, taro, bananas, and sweet potato. The vegetation was cleared in May 1992 followed by burning in June 1992. Four plots of 15 x 10 m each were laid out as a randomized complete block design. At the side and upper boundaries of each plot, a 15 cm

***Table 1.* Some chemical and physical properties of the soils at the experimental site[1].**

Sampling depth(m)	pH H_2O (1:5)	Organic C (g kg^{-1})	Total N (g kg^{-1})	Avail. P (Olsen) (mg kg^{-1})	CEC pH7 (mmol$_c$ kg^{-1})	Exchangeable cations (mmol$_c$ kg^{-1})			Particle size fractions (g kg^{-1})		
						Ca	Mg	K	sand	silt	clay
0-0 10	6.2	27.9	2.4	5.6	289	267	92	10.2	570	260	170
0. 10-0.26	6.2	28.6	2.6	2.5	276	236	95	9.6	570	200	230
0.26-0.40	6.2	13.2	1.3	0.6	292	223	106	5.5	490	190	320
0.40-0.69	5.6	7.7	0.8	0.3	194	221	107	1.7	480	240	280
0.69-0.91	5.4	8.2	1.2	0.4	66	231	104	2.2	510	180	320
>0.91	5.5	6.8	0.8	0.5	33	234	99	2.2	510	160	330

[1] Data from pit samples taken on 05-04-1996 in a nearby field under fallow vegetation

zinc strip was placed 8 cm into the soil. At the lower end of the plots, a PVC gutter and boxes were installed for the collection of surface runoff and sediment. The collection devices were capable of containing the entire volume of runoff and erosion from one week. In June 1992, all four plots were planted with six months old *Leucaena leucocephala* seedlings at a spacing of 2 x 2 m (37 trees per plot). Two plots were intercropped with sweet potato (*Ipomoea batatas* L.) at 0.5 m x 0.5 m spacing (600 plants per plot).

Data collection and analysis

From 1992 to 1994 runoff and erosion were measured weekly from the collection boxes. Sediment samples were taken to the laboratory, airdried and weighed. Rainfall was measured daily using a standard rain gauge in an open area near the study site. For the presentation of the data, daily rainfall, weekly surface runoff and erosion were accumulated for each month and averaged for the two plots. The first sweet potato was planted with the *Leucaena* in June 1992. Sweet potato tubers were harvested every four months and fresh yield was determined. Planting of sweet potato cuttings was done immediately after the harvest. In total five crops of sweet potato were grown. Weeding was done manually each month in the intercropped plots and every two months in the sole *Leucaena* plots. The height of all *Leucaena* trees was measured at 6, 7, 8, 10, 13 and 18 months after planting.

The soils of each plot were sampled (0-0.15 and 0.15-0.45 m depth) at the beginning of the experiment prior to the burning of the vegetation, and at 2, 12 and 25 months thereafter. Samples were composites of nine locations within each plot. Soils were analyzed at the National Analysis Laboratory in Lae for the following properties: pH water (1:5), total N (Kjeldahl), available P (Brayl) and exchangeable Ca, Mg and K (1*M* NH_4OAc at pH 7). Samples from the soil pit (Table 1) were analyzed at the National Chemistry Laboratory in Port Moresby.

Monthly rainfall, surface runoff and erosion were skewly distributed and the data were log-transformed before regression analysis (Mead *et al.* 1993). Regression analysis was carried out using Statistix ver. 4.1 software. Standard errors of soil chemical properties and analysis of variance of the height of *Leucaena* were also calculated with Statistix software.

RESULTS

Runoff and erosion

During the first year, surface runoff for the intercropped plots was 817 mm and 537 mm for the sole *Leucaena* plots which was equivalent to 37% and 24% of the total rainfall. Surface runoff in the second year was 1003 mm and 668 mm for the intercropped and sole *Leucaena* plots respectively (Table 2). In the second year surface runoff was relatively higher and 55% and 36% of the total rainfall for the intercropped and sole *Leucaena*. The difference in runoff of intercropped and sole *Leucaena* was significant ($P<0.05$).

Surface erosion was 3.9 t ha^{-1} from the intercropped plots and 3.5 t ha^{-1} from the sole *Leucaena* plots during the first year. Erosion decreased to 2.9 t ha^{-1} in the intercropped plots and to 2.2 t ha^{-1} under sole *Leucaena* in the second year despite the relative higher surface runoff. The difference in erosion between intercropped and sole *Leucaena* was not

***Table 2.* Surface runoff and erosion under intercropped and sole *Leucaena*.**

	rainfall (mm)	intercropped		sole *Leucaena*	
		surface runoff (mm)	erosion (t ha^{-1})	surface runoff (mm)	erosion (t ha^{-1})
August 1992-July 1993	2212	817	3.9	537	3.5
August 1993-July 1994	1833	1003	2.9	668	2.2
mean	2023	910	3.4	603	2.9

Figure 1. **Relation between rainfall and runoff (A), and runoff and erosion (B) in intercropped and sole *Leucaena* plots. (All axis on log scales).**

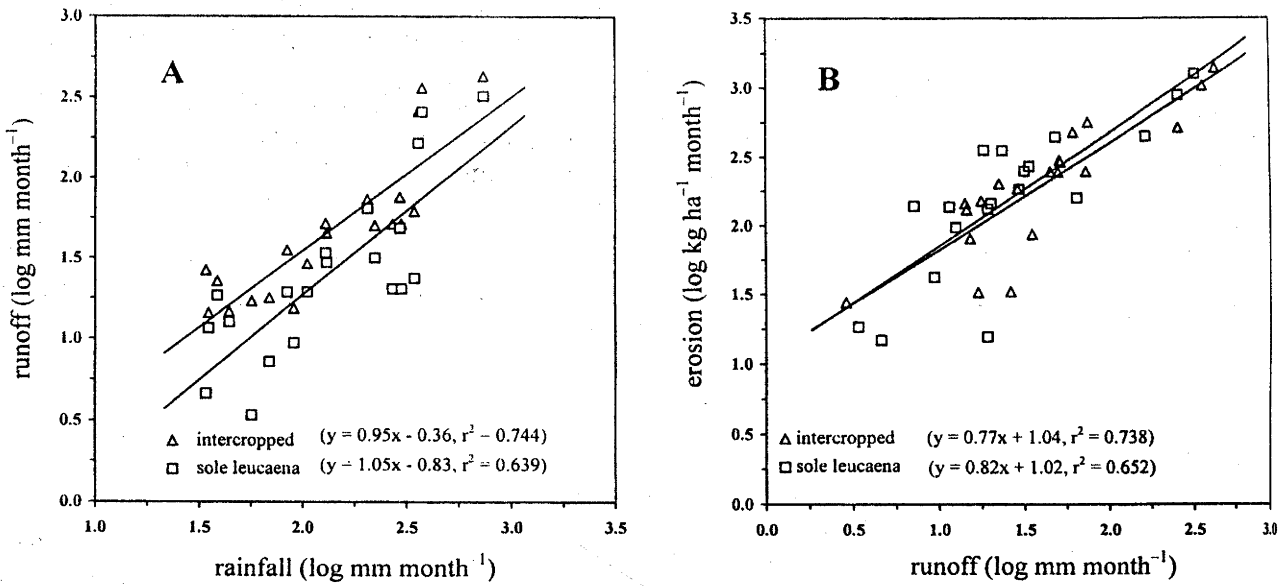

Table 3. **Soil chemical properties of intercropped and sole *Leucaena* at different sampling times.**

		intercropped					sole *Leucaena*				
months after *Leucaena* planting	depth (m)	-1	+2	+12	+25	SED[a]	-1	+2	+12	+25	SED[a]
pH H_2O (1:5)	0-0.15	6.0	5.8	5.7	5.6	0.07	6.2	5.9	5.7	5.8	0.09
	0.15-0.45	5.9	5.3	5.7	5.4	0.12	5.9	5.7	5.3	5.5	0.11
Total N (g kg^{-1})	0-0.15	4.8	2.8	3.3	3.5	0.4	3.6	3.8	4.0	3.7	0.2
	0.15-0.45	1.8	1.6	2.0	1.7	0.1	1.8	2.3	0.6	2.5	0.3
Available P (Brayl) (mg kg^{-1})	0-0.15	9	11	8	5	1.5	9	10	5	3	1.2
	0.15-0.45	2	6	3	1	0.8	4	6	3	<1	0.8
Exchangeable Ca ($mmol_c$ kg^{-1})	0-0.15	305	270	320	320	11	265	280	285	300	21
	0.15-0.45	230	230	280	270	11	210	295	270	270	13
Exchangeable Mg ($mmol_c$ kg^{-1})	0-0.15	82	80	67	68	6	78	60	89	84	5
	0.15-0.45	84	84	58	66	8	85	58	95	76	8
Exchangeable K ($mmol_c$ kg^{-1})	0-0.15	5.5	5.5	4.1	2.6	0.9	6.5	4.0	4.0	3.6	0.5
	0.15-0.45	2.0	1.5	1.5	1.2	0.3	2.0	1.5	1.7	1.8	0.1

[a] Standard error of the difference in means (*7df*).

significant (P=0.17).

In the intercropped plots, erosion per mm of surface runoff was 0.0047 t ha^{-1} in the first year and 0.0028 t ha^{-1} in the second year whereas under sole *Leucaena* this decreased from 0.0065 to 0.0032 t ha^{-1} per mm of surface runoff.

Rainfall-runoff-erosion

Monthly surface runoff and rainfall were well correlated for both treatments (Figure 1). The same amount of monthly rainfall resulted in more runoff in the intercropped plots, but the slopes of the regression equations suggest that higher rainfall resulted in relative more runoff in the sole *Leucaena* plots. About 74% and 64% of the variation in monthly runoff in the intercropped and sole *Leucaena* plots respectively, could be explained by rainfall.

Likewise, monthly surface runoff and erosion were correlated. The slope and y-intercept were approximately the same for intercropped and sole *Leucaena* plots. About 74% of the variation in monthly erosion in the intercropped and 65% in the sole *Leucaena* plots was due to the runoff.

Changes in soil chemical properties

The pH of the top and subsoil of both the intercropped and sole *Leucaena* plots, decreased significantly with time (P=0.05) and the decrease was 0.4 to 0.5 unit (Table 3). Total nitrogen decreased in the topsoils of the intercropped plots but did not change significantly in the subsoils. Under sole *Leucaena*, total nitrogen decreased in the subsoil whereas no changes were found in the topsoils. Available phosphorus decreased in the topsoils under intercropped and sole *Leucaena* to low levels. Subsoil phosphorus increased between the first and second sampling but decreased to a very low level at 12 and 25 months after the *Leucaena* planting. No significant changes were found in the topsoil exchangeable calcium levels but subsoil calcium levels increased under both intercropped and sole *Leucaena*. Initial exchangeable magnesium levels under intercropped and sole *Leucaena* were not significantly different from 25 months thereafter. Exchangeable potassium was significantly lower at 25 months than the initial sampling for both top and subsoils of the intercropped and sole *Leucaena* plots.

Leucaena growth and sweet potato yield

There were no statistical differences (P>0.05) in the height of *Leucaena* when intercropped or grown as a sole crop. Three months after planting, the *Leucaena* trees were about 0.5 m but one year later the trees were 4.3 m in the intercropped and 5.3 m in the sole *Leucaena* plots (Table 4).

Table 4. **Height (m) of intercropped and sole *Leucaena* (±1 standard deviation)**

age (months)	Intercropped		sole *Leucaena*	
9	0.51	±0.24	0.59	±0.21
10	0.75	±0.29	0.79	±0.28
11	1.32	±0.43	1.60	±0.26
13	1.76	±0.49	2.21	±0.81
16	3.31	±0.79	3.89	±0.71
21	4.34	±1.09	5.28	±1.35

Yields of sweet potato decreased with time. The first crop harvested at four months yielded 4.2 t ha^{-1} (fresh tuber weight), followed by 3.9 t ha^{-1} (9 months), 2.7 t ha^{-1} (14 months) and 2.2 t ha^{-1} at 19 months after the *Leucaena* planting. The fifth and last planted crop was harvested at 23 months and yielded only 0.2 t ha^{-1}.

DISCUSSION

Surface runoff and erosion from the intercropped plots was on an average 307 mm yr^{-1} and 0.5 t ha^{-1} yr^{-1} higher than under sole *Leucaena*. This is probably due to the higher frequency of weeding and the harvest operations in the intercropped plots. Similar observations were made by Kijkar (1985) who also found higher surface runoff and erosion from teak plots.

It was found that surface runoff was relatively higher in both intercropped and sole *Leucaena* plots in the second year, but that did not result in more erosion. The closing canopies of the *Leucaena* reduced splash erosion but infiltration was apparently also reduced. This is contrary to what is commonly found (e.g. Young 1989; Sanchez 1995) and hitherto not fully understood.

Average erosion from the intercropped plots was below 4 t ha^{-1} yr^{-1}. Such erosion rates were also obtained in fallow plots with the same slope in Chimbu Province (Papua New Guinea) whereas erosion rates of 13.6 t ha^{-1} yr^{-1} were recorded from sweet potato gardens in the Southern Highlands (Bleeker 1983). Erosion under both intercropped and sole *Leucaena* was below the FAO's acceptable lower limit of 10 t ha^{-1} for water-induced erosion (FAO 1978). Young (1989) mentioned that erosion rates of 2 to 10 t ha^{-1} yr^{-1} are moderate and also Lal (1994) considers that erosion rates below 5 t ha^{-1} yr^{-1} are slight.

Levels of plant nutrients decreased under both intercropped and sole *Leucaena*. The decrease is possibly the result of nutrient uptake by the *Leucaena* and the sweet potato. Part of the decline in nutrients may have been caused by the loss of topsoil as such loss may have major soil fertility implications (Sanchez 1995; Zöbisch *et al.* 1995).

Sweet potato yields decreased with time and four crops with yields of 2.2 to 4.2 t ha^{-1} could be grown between the *Leucaena* before competition for water, nutrients and solar radiation decreased yield levels below 0.5 t ha^{-1}. Overall yields were low and confirm the data from Louman and Hartemink (1998).

CONCLUSIONS

Intercropping *Leucaena* with sweet potato resulted in slightly higher surface runoff and erosion as compared to sole *Leucaena* but levels of erosion were very low in both treatments (< 4 t ha^{-1} yr^{-1}). Changes in soil fertility were similar in intercropped and sole *Leucaena* plots. The study has shown that intercropping *Leucaena* with sweet potato during the first two years does not significantly increase erosion, affect soil fertility and the growth of *Leucaena* as compared to sole *Leucaena* cropping.

ACKNOWLEDGEMENTS

This research was funded through the Research Committee of the University of Technology in Lae. Useful comments on this paper were provided by Dr. Mike Bourke (ANU-Canberra) and Mr. Fred Grieshaber (NAL-Lae).

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