The use of forages for soil fertility maintenance and erosion control in cassava in Asia

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Introduction

Cassava (*Manihot esculenta* Crantz) has the reputation to extracts large amounts of nutrients from the soil. However, Howeler (1991) and Putthacharoen et al. (1998) have shown that on an area basis, less nitrogen (N) and phosphorus (P) are removed in the harvested cassava roots than in the harvested products of most other crops, while the amount of potassium (K) removed in the harvested roots is similar to that removed by many other crops. Thus, continuous cassava production on the same land without nutrient inputs is likely to result in depletion of soil K, followed by that of N, and finally P. To maintain soil productivity, nutrients lost from the system should be compensated by application of chemical fertilisers and animal manures, by fallowing of natural vegetation, or by 'improved' fallows using mainly forage legumes as green manures and cover crops, or as hedgerows in alley cropping. In the latter case, the legumes add N to the system through biological N-fixation, and recycle P and K by absorbing these nutrients from the lower soil strata and returning them to the soil surface in leaf litter, in leaf pruning, or plant residues. After cutting, burning, mulching or incorporation of the vegetation, the surface soil tends to be enriched with these nutrients, which enhances the production of crops.

When crops are grown on slopes, heavy rains may cause dislodging and movement down-slope of soil particles resulting in soil erosion. Over time, this will reduce soil depth and a loss of soil productivity due to the loss of organic matter (OM), nutrients and beneficial soil microorganisms, such as *mycorrhiza*. Putthacharoen et al. (1998), Wargiono et al. (1998) and Howeler (1995) have shown that production of cassava tends to result in more erosion than that of other crops, mainly because cassava is planted at a wide spacing and has a slow initial growth, resulting in poor protection of the soil from direct rainfall impact during the first three months of the crop cycle. However, it was found (Howeler 1987 and 1994; Ruppenthal et al. 1997) that erosion can be markedly reduced by soil/crop management practices, such as minimal tillage, mulching, contour ridging, fertilisation, intercropping, closer plant spacing, or the planting of cover crops or contour hedgerows of grasses or leguminous species.

The objective of this paper is to review research conducted in Asia on the use of forage species for improving soil fertility through green manuring, alley cropping and cover cropping, or for reducing erosion by the planting of contour hedgerows in cassava fields. The research summarized in this paper spans a 11-year period, from 1987 to 1998, and was conducted in three locations in Thailand and one location in Indonesia.

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Materials and methods

The principal climatic and soil conditions at the experimental sites are summarized in Table 1. Most experiments were conducted in Thailand, at Rayong Field Crops Research Centre in Huay Pong, Rayong; at the King's Project site, in Pluak Daeng, Rayong; and at Kasetsart University Research Station in Khaw Hin Sorn, Chasoengsao. These sites have similar climatic and soil conditions, characterized by a year-round hot climate, a 6-month dry season, and sandy clay or sandy clay loam soils with low levels of OM, and intermediate levels of soil nutrients. In Indonesia, the experiment was conducted at Jatikerto Experiment Station in Malang district of East Java. The soil is derived from volcanic ash, has a clay texture, a slightly acid pH, and is low in OM and P, but high in Ca, Mg and K.

The experimental methods used in each experiment are summarized in Table 2, and will be discussed in more detail below together with the results obtained.

Table 1a. Principal climatic of the experimental sites in Thailand and Indonesia.

Experimental sites	Elevation (masl)	Annual rainfall (mm)	Rainy season	Mean air temp. (^{0}C)
1. Rayong Field Crops Research Centre, Rayong Thailand	20	1350	May-Oct	28
2. Pluak Daeng, Rayong, Thailand		1200	May-Oct	28
3. Khaw Hin Sorn, KU Exp. Station., Chachoengsao, Thailand	50	1200	May-Oct	28
4. Jatikerto, Brawijaya Univ. Exp. Station, Malang, Indonesia	400	2000	Oct-May	27

Table 1b. Principal soil characteristics of the experimental sites in Thailand and Indonesia.

	pH	OM	P	Al	Ca	Mg	K	Al-sat.	Texture	sand	silt	clay
		%	ppm	me/100g				%		%	%	%
1. Rayong	5.0	1.3	8.8	0.20	1.10	0.15	0.11	13	sandy clay loam	63	8	29
2. Pluak Daeng	6.4	0.8	8.0	0	1.12	0.17	0.22	0	sandy clay	67	15	18
3. Khaw Hin Sorn	6.2	1.6	7.4	0	2.13	0.34	0.22	0	sandy clay	69	14	17
4. Jatikerto	5.9	1.0	1.6	0.20	7.52	2.90	1.16	0	clay	25	25	50

Table 2. Experimental methods used in the experiments.

Location	Years	Cassava variety	Planting method	Forage species and methods used
Rayong	1987-1988	-	evaluation	32 accessions of leguminous species
Pluak Daeng	1988-1991	Rayong 1	green manuring	10 green manure species
Pluak Daeng	1991-1994	Rayong 1	green manuring	6 green manure species x 2 management practices
Rayong	1994-1998	Rayong 90	green manuring	4 green manure species x 3 management practices
Pluak Daeng	1988-1990	Rayong 1	cover cropping	9 forage legumes
Pluak Daeng	1991-1993	Rayong 1	cover cropping	7 forage legumes x 2 cassava spacings
Rayong	1990-1991	-	evaluation	12 accessions of leguminous shrubs
Malang	1991-1995	Faroka	alley cropping	2 tree legumes as hedgerows, 1 cover crop, intercrop, grass hedgerows
Khaw Hin Sorn	1996-1998	KU-50	hedgerows	15 grass species

Results and discussion

The use of forages as green manures for soil fertility improvement

Adaptation of grain and forage legumes to conditions in Rayong, Thailand

Green manures can be effective only if they are productive and well adapted to the local soil and climatic conditions. To determine their productivity under the conditions in which cassava is grown in Thailand, 32 accessions of grain and forage legumes, including some leguminous tree species, were planted at the Rayong Field Crops Research Centre in Huay Pong, Rayong, Thailand in 1987/88.

Table 3 shows some growth parameters as well as the nutrient uptake of the species.

Table 3. Growth and nutrient uptake of leguminous species grown at Rayong Field Crops Research Centre, Rayong, Thailand in 1987.

	Days to 50% flowering	Seed yield (t/ha)	Stem + leaf weight[1] (t/ha)		Nutrient content (kg/ha)		
			fresh	dry	N	P	K
Grain legumes							
Peanut (Tainan 9)	32	0.48	12.8	3.50	42	6	73
Mungbean (U-Thong 1)	32	0.24	3.5	1.00	10	1	13
Cowpea (local variety)	33	1.55	8.6	1.69	47	5	39
Cowpea (TVX 1193-059)	36	3.78	15.7	3.09	83	9	69
Soybean (SJ 5)	32	0.44	2.6	0.94	15	3	14
Green manures							
Sesbania aculiata from IRRI	60	0.60	19.3	7.09	80	13	71
Sesbania aculiata	67	0.85	27.5	12.31	170	17	113
Sesbania speciosa	127	0.52	55.6	19.37	281	27	213
Sesbania rostrata from IRRI	67	0.78	16.0	6.65	89	18	66
Sesbania rostrata	71	1.89	19.1	7.69	81	8	78
Indigofera sp.	106	1.59	42.6	17.69	457	32	195
Canavalia ensiformis	50	1.30	22.4	3.91	113	9	59
Mucuna sp. from CIAT	131	0.30	38.4	8.16	224	16	135
Mucuna fospeada	122	1.82	42.2	11.31	244	20	119
Crotalaria juncea	67	0.00	21.1	9.50	130	11	86
Crotalaria spectabilis (Brazil)	60	0.15	28.0	8.00	134	14	112
Crotalaria spectabilis (Colombia)	54	0.06	20.3	5.56	95	13	31
Crotalaria mucronata 7790	60	0.38	38.6	10.84	295	17	157
Crotalaria mucronata 9293	54	0.02	21.6	6.06	120	13	100
Lablab purpureus	173	0.94	29.2	7.44	171	19	119
Pigeon pea from ICRISAT	54	0.35	25.5	10.16	240	23	112
Pigeon pea from USA	184	0.25	105.9	40.34	980	77	867
Cover crops							
Macroptilium atropurpureum	50	0.22	43.8	11.28	235	20	214
Mimosa sp.[2]	147	0.87	50.9	18.34	262	29	248
Calopogonium mucunoides	149	0.06	22.1	7.37	159	20	103
Pueraria phaseoloides	146	-[3)]	33.4	8.75	209	21	148
Stylosanthes hamata	50	1.22	29.5	10.94	237	14	113
Centrosema pubescens	153	0.09	13.4	3.97	101	11	66
Alley crop hedgerow species							
Sesbania javanica	114	0.14	21.0	7.91	137	12	85

[1)] At cutting (5 months); soybean, peanut and mungbean at harvest of each species.
[2)] Mimosa sp. (a thornless variant of *M. invisa*).
[3)] Drought at flowering caused no pod set.

From the results obtained the most promising species were separated into four groups according to their specific potential usage:

- For green manures: *Sesbania speciosa*, *S. aculeata*, *S. rostrata*, *Crotalaria juncea*, *C. mucronata*, *C. spectabilis*, *Indigofera* sp., *Canavalia ensiformis* (sword bean), *Mucuna fospeada* (velvet bean) and *Cajanas cajan* (pigeon pea).
- For cover crops: *Centrosema pubescens*, *Macroptilium atropurpureum* (siratro), *Mimosa* sp. (a spineless variant of *M. invisa*), *Stylosanthes hamata* and *Indigofera* sp.
- For intercropping: peanut, mungbean, cowpea and soybean.
- For alley cropping: *Sesbania aculeata*, *S. javanica* and perennial pigeon pea.

Green manuring of cassava with forage legumes in Pluak Daeng, Thailand

The use of forage legumes as green manures to maintain soil fertility in sandy clay soils was studied by planting 10 green manure species at the beginning of the wet season in Pluak Daeng of Rayong province. After 3-4 months the above-ground parts were cut and incorporated into the soil before planting cassava in the mid to late wet season. Cassava did not receive any fertilisers, except in one of the two treatments without green manure which received 100 kg N and 50 K_2O/ha. The crop was harvested after about 8 months at the start of the next wet season. The trial was repeated in a similar fashion in 1989/90 and 1990/91, except that green manures were mulched on the soil surface and cassava was planted without land preparation.

Table 4 shows the productivity of the green manures and their effect on cassava yield during the three years of testing. There was a significant effect of green manure application on cassava yields in the first two years, but the effect was not significant in the last year. *Crotalaria juncea* and *Canavalia ensiformis* were the most productive species, and the most effective in recycling nutrients (Tongglum et al. 1992), while incorporation or mulching of *Crotalaria juncea* usually resulted in the highest cassava yields; these yields were similar to those obtained with chemical fertilisers. Other promising species were *Mucuna fospeada* and *Canavalia ensiformis*. Nevertheless, in the first two years, cassava yields were extremely low because cassava could only be planted late in the rainy season after the green manures had been incorporated or mulched; as such, cassava suffered from drought stress during much of the growth cycle. In the third year, cassava was not harvested until Aug 1991 (11 months), resulting in much higher yields, but no significant response to green manure application.

Table 4. The effect of green manures on cassava yield in three trials in Pluak Daeng, Thailand.

Green manure treatments[1)]	DM green manures (t/ha)			Cassava fresh root yield (t/ha)		
	1988/89	1989/90	1990/91	1988/89	1989/90	1990/91
No green manure, no fertiliser	-	-	-	3.21 cd	5.75 bcd	16.36
Sesbania rostrata, no fertiliser	9.71 b	3.46 b	9.91 b	9.29 a	5.37 bcd	15.04
Sesbania speciosa, no fertiliser	2.58 ef	2.15 b	9.73 b	5.61 abcd	4.46 cd	17.52
Sesbania aculeata, no fertiliser	4.20 de	2.54 b	7.58 b	5.19 bcd	4.42 cd	13.23
Crotalaria juncea, no fertiliser	13.46 a	6.88 a	24.79 a	9.04 ab	8.83 a	17.29
Crotalaria mucronata CIAT 7790, no fertiliser	6.77 c	2.86 b	10.36 b	6.71 abc	5.17 bcd	11.77
Crotalaria spectabilis, no fertiliser	5.49 cd	2.98 b	12.75 ab	5.81 abcd	3.96 d	17.64
Canavalia ensiformis, no fertiliser	6.63 c	6.96 a	24.79 a	5.37 bcd	7.00 abc	14.67
Indigo, no fertiliser	6.36 c	3.21 b	10.94 b	5.37 bcd	5.08 bcd	16.61
Mucuna fospeada, no fertiliser	5.66 cd	2.70 b	10.74 b	5.21 bcd	6.08 abcd	16.45
Pigeon pea (ICRISAT), no fertiliser	2.11 f	3.46 b	2.29 b	2.06 d	4.50 cd	14.79
No green manure, with fertilisers[2)]	-	-	-	8.75 ab	7.71 ab	17.04
F-test	**	**	**	**	*	NS

1) Green manures were planted in May/June, cut in Aug/Sept and cassava planted in Oct, harvested after 8-9 months in the first two years and after 11 months in the third year.
2) 100 N, 0 P, 50 kg/ha K_2O.

Analyses of soil samples taken before planting and after harvest of cassava indicate that green manures had no significant effect on pH, OM and available P or exchangeable K (CIAT, 1992). In all treatments, soil pH gradually decreased from 6.6 to 5.5, OM decreased slightly from 1.0 to 0.8 %, P was quite variable, while available K decreased from 95 to about 30 ppm during three years of consecutive cropping.

A similar experiment was conducted for three years (1991 to 1994) in an adjacent field in Pluak Daeng using six species of green manures. These were again planted in the early wet season (May/June), cut after about 3 months, and (in subplots) either mulched on the soil surface or incorporated into the soil with a hand tractor. In the mulched subplots cassava was planted without further land preparation. Cassava was planted in the mid to late rainy season (Aug/Sept) and harvested after 9-10 months. For comparison, two additional plots without green manures were planted at the more traditional planting time at the start of the rainy season (May/June); these were also harvested after 9-10 months. At both planting times one of the two check plots without green manures received 100 kg N and 50 K_2O per hectare as fertilisers.

Table 5 shows that planting in the early rainy season resulted in much higher cassava yields than planting towards the end of the rainy season. Application of NK fertilisers increased yields but not significantly. Among the six green manures, *Crotalaria juncea* was consistently the most productive species, while *Sesbania rostrata* was the least productive. *Crotalaria juncea,* either when mulched or incorporated, also produced the highest cassava yields. While these yields were higher than those planted in September with fertilisers, they were not significantly different from yields obtained without fertiliser when cassava was planted in the early wet season, and they were considerably lower than those obtained with fertilisers and planted in May/June. Soil analyses again indicate that incorporation or mulching of green manures had no significant effect on soil fertility parameters. This indicates that nutrients leached from the decomposing green manures were directly absorbed by cassava roots without having a long-term effect on soil fertility.

Table 5. Effect of cassava planting time, fertilisation and green manuring on green manure production and cassava yields in Pluak Daeng, Thailand (dates are mean values for three cropping cycles, 1991/92, 1992/93 and 1993/94).

	Green manure yield – DM (t/ha)		Cassava fresh root yield (t/ha)		
Green manure treatments	**incorporated**	**mulched**	**incorporated**	**mulched[1]**	**Mean**
No green manure, June planting, no fertiliser	-	-	11.06	9.13	10.09 ab
No green manure, June planting, with fertiliser[2)]	-	-	13.69	13.17	13.43 a
No green manure, Sept. planting, no fertiliser	-	-	5.76	4.45	5.11 cd
No green manure, Sept. planting, with fertiliser[2)]	-	-	6.49	5.57	6.03 cd
Sesbania rostrata, Sept. planting, no fertiliser	0.84	1.11	5.25	3.63	4.44 d
Mucuna fospeada, Sept. planting, no fertiliser	3.08	3.78	7.44	9.41	8.42 bc
Crotalaria juncea, Sept. planting, no fertiliser	6.22	6.92	9.92	10.47	10.20 ab
Canavalia ensiformis, Sept. planting, no fertiliser	3.27	3.64	6.83	6.94	6.88 bcd
Cowpea, Sept. planting, no fertiliser	2.10	2.97	7.40	4.61	6.00 cd
Pigeon pea, Sept. planting, no fertiliser	3.10	3.57	9.31	6.17	7.74 bcd
Mean	3.10	3.66	8.32A	7.36A	
F-test for cassava yield: main plots (A) NS; green manure treatments (B) **; AxB NS					

[1] cassava planted without land preparation.

[2] 94 N, 0 P, 50 kg/ha K_2O.

From these two experiments conducted in Pluak Daeng it was concluded that among the green manures tested, *Crotalaria juncea* was the most productive and the most effective in increasing cassava yields; that incorporation resulted in slightly higher yields than mulching (not statistically significant); and that some green manures were as effective or even more effective than chemical fertilisers in increasing yield. However, under the climatic conditions of Thailand, which has a 6-month dry season, the traditional use of green manures is impractical, since the better part of the rainy season is used for production of green manures, while the following cassava crop produces low yields due to drought stress in the dry season.

Alternative management of green manure species in Rayong, Thailand

To overcome some of the above-mentioned constraints alternative management practices were tested in a green manure trial conducted at Rayong Research Centre from 1994 to 1998, using *Crotalaria juncea, Canavalia ensiformis,* pigeon pea and cowpea as the green manures. Three methods of green manure management were tested: a) green manures were intercropped with cassava, pulled out at two months after planting (MAP) and mulched between cassava rows; b) green manures were interplanted into a mature cassava stand at 7 MAP; they were pulled up and mulched at the time of next cassava planting; or 3) green manures were grown as a conventional green manure crop before being pulled up at 3-4 MAP and mulched, after which cassava was planted without further land preparation and left to grow for 18 months. The last method resulted in a two-year crop cycle, while in methods 1 and 2 cassava was harvested at 11 months for a normal one-year crop cycle.

The results, shown in Table 6, indicate that *Crotalaria juncea* usually had the highest dry matter (DM) production, followed by pigeon pea or cowpea. Pigeon pea was particularly productive as a green manure crop when interplanted at 7 MAP, in which case the green manure remained in the field during the dry season. Because of their high DM production, *Crotalaria* and pigeon pea were the most effective in recycling nutrients.

In the first cycle almost all green manure treatments increased cassava yields compared with the check without green manure (T_1); however, these yields were still below those obtained with a higher fertilisation rate (T_2). In the second cycle, intercropping or interplanting of the green manures had no significant effect on cassava yields, which were again considerably below that obtained with a higher rate of fertilisation (T_2). Leaving cassava grow for 18 months after a conventional green manure crop (T_{11}-T_{14}) resulted in very high yields while having little effect on root starch content. This may be an effective way for farmers to reduce production costs, since land preparation, weeding and harvesting is done only once in two years, while total production from one 2-year cycle was only slightly lower than that of two 1-year cycles.

Again, there were no consistent effects of any of the green manure treatments on soil pH, organic matter (OM), available P or exchangeable K. Thus, while green manuring may have some short-term benefits in terms of crop productivity, the long-term effects on soil fertility are not very clear. Whenever labour is scarce or expensive, such as in Thailand, farmers will probably prefer to maximize their yields through the use of chemical fertilisers instead of green manures.

Nevertheless, Paisarncharoen *et al*. (1990) reported that incorporation of vegetative cowpea (Tita-3) increased significantly the yield of the following cassava crop during five consecutive years in Khon Kaen in Northeast Thailand. Incorporation of *Crotalaria juncea* also increased yields, but not significantly, while pigeon pea had little beneficial effect (Sittibusaya et al. 1995).

Table 6. Effect of fertiliser application, three alternative green manure practices and four different species on green manure production and nutrient uptake, as well as on the yield of cassava (cv. Rayong 90) grown for two consecutive cropping cycles at Rayong Research Centre in Thailand from 1994 to1998.

	Treatments[1]	DM yield green manures (t/ha)		Nutrient content of green manures (kg/ha) N		P		K		Cassava fresh root yield (t/ha)	
		1st[2)]	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
1.	Cassava without green manure, with 156 kg/ha 13-13-21 fertiliser	-	-	-	-	-	-	-	-	17.6	30.1
2.	Cassava without green manure, with 468 kg/ha 13-13-21 fertiliser	-	-	-	-	-	-	-	-	29.8	40.4
3.	Cassava intercropped with *Crotalaria juncea*, mulched at 2 MAP	1.9	4.7	44.7	94.9	3.0	12.7	27.6	31.1	23.8	29.2
4.	Cassava intercropped with *Canavalia ensiformis*, mulched at 2 MAP	0.9	1.8	20.1	51.7	2.4	6.6	14.6	25.9	26.9	27.8
5.	Cassava intercropped with pigeon pea, mulched at 2 MAP	1.1	2.1	27.0	48.7	2.2	6.7	12.5	19.0	21.4	27.0
6.	Cassava intercropped with cowpea, mulched at 2 MAP	-	2.8	-	53.7	-	7.2	-	27.1	20.3	18.8
7.	Cassava interplanted with *Crotalia juncea* at 7 MAP and mulched	9.9	1.2	262.1	21.7	23.7	4.6	102.9	7.4	8.8	31.4
8.	Cassava interplanted with *Canavalia ensiformis* at 7MAP and mulched	1.5	0.7	36.6	16.0	4.1	3.1	28.0	8.2	22.8	24.2
9.	Cassava interplanted with pigeon pea at 7 MAP and mulched	8.9	2.3	221.7	45.5	20.0	7.3	108.8	15.9	15.9	28.8
10.	Cassava interplanted with cowpea at 7 MAP and mulched	-	0.7	-	14.2	-	2.9	-	7.6	17.3	27.0
11.	*Crotalaria juncea* green manure, mulched, cassava for 18months	1.4	4.4	39.9	79.9	3.6	17.7	14.7	31.6	46.2[3)]	49.0[3)]
12.	*Canavalia ensiformis* green manure, mulched, cassava for 18months	0.9	1.4	18.4	45.7	2.3	7.2	15.8	17.2	42.9	43.8
13.	Pigeon pea green manure, mulched, cassava for 18months	1.1	2.7	25.6	68.7	2.3	13.2	12.8	21.7	38.8	46.0
14.	Cowpea green manure, mulched, cassava for 18months	-	2.9	-	68.2	-	12.6	-	31.0	38.9	46.3

1) Fertiliser applied 13-13-21 fertiliser kg/ha. In T3-T14 cassava received 156 kg/ha 13-13-21 fertiliser (like T1). In T3-T6 cassava was intercropped with 1 row of green manure, which was pulled out and mulched at 2 MAP; cassava was harvested at 11 months for a total crop cycle of 12 months. In T7-T10 the green manures were inter-planted in the cassava stand at 7 MAP; they remain after the cassava harvest and were pulled up and mulched at time of next cassava planting; cassava was harvested at 11 months for a total crop cycle of 12 months. In T11-14 the green manures were planted, pulled out and mulched at 3-4 months, after which cassava was planted and remains in the field for 18 months for a total crop cycle of 24 months. In the first cycle, T6, T10 and T14 had *Mucuna pruriens* as the green manure, but this species did not germinate well and was replaced by cowpea in the 2nd cycle.

2) 1st and 2nd refer to the two cropping cycles.

3) High yields in T11-14 is mainly due to a longer (18 months) cropping cycle compared with a normal 1-year (11 months) cropping cycle for the other treatments.

The use of forages as cover crops to improve fertility and reduce erosion

Erosion losses in cassava fields were found to be high (Puttacharoen et al. 1998) mainly because much of the soil surface remains exposed to the direct impact of raindrops during the first 3-4 months after planting. This problem can be reduced by minimum tillage (Reining, 1992), application of mulch (Evangelio et al. 1995), intercropping (Reining, 1992), or by the use of forage legumes as a cover crop for cassava (Ruppenthal, 1995). These practices can be very effective in controlling erosion (Howeler, 1995) and may also improve soil fertility, but they have negative aspects such as weeding problems, high labour requirements, or competition effects from the cover crops. To determine the potential of several forage legumes for their use as cover crops in cassava, various experiments were conducted in Thailand.

Cover cropping of cassava with forage legumes in Pluak Daeng, Thailand

After evaluating a large number of forage species for adaptation to soil and climatic conditions in Rayong, Thailand, some species were identified as potential cover crops for use with cassava (Table 3). Nine leguminous forage species were planted in double rows in between rows of cassava, cv. Rayong 1, spaced at 1.80 x 0.55 m. Cassava received 156 kg/ha of 15-15-15 fertiliser.

All forage species established well, resulting in complete soil cover in 3-4 months after planting, except for *Arachis pintoi* and *Stylosanthes hamata,* which established more slowly. In the first year, cover crops were not cut back, resulting in competition with cassava, both for light and for soil moisture during the dry season. After the first cassava harvest, all cover crops were slashed back and mulched. Plots were subdivided and cassava was replanted at a spacing of 1.10 x 0.90 m in 60-cm wide strips prepared either with hand tractor or by spraying the cover crops with Paraquat. The same methodology was used in the third year. In the second and third year cover crops were regularly slashed back at 20 cm above ground level to reduce competition with cassava.

Nevertheless, Table 7 shows that cassava yields were low and severely affected by competition from the cover crops. Most competitive was *Stylosanthes guianensis,* followed by *Centrosema pubescens. Stylosanthes hamata and Arachis pintoi* were not very competitive during the first year of establishment, but became very competitive in subsequent years. Least competitive was *Centrosema acutifolium*, but this was partly due to less vigorous growth resulting in only partial soil cover.

Table 7. Effect of intercropping cassava with leguminous cover crops on the yield of cassava, cv. Rayong 1, in three trials in Pluak Daeng, Thailand.

	DM cover crops (t/ha)		Cassava fresh root yield (t/ha)[1]		
Cover crop treatments	**1988/89[2]**	**1990/91[3]**	**1988/89**	**1989/90**	**1990/91**
No cover crop	-	-	11.68 a	7.79 a	19.62 a
Stylosanthes hamata	1.74 d	1.68 ab	10.27 ab	3.91 c	4.45 de
Stylosanthes guianensis	9.22 a	2.19 a	3.21 d	6.56 ab	0.83 e
Arachis pintoi	0.87 d	-	8.46 bc	6.56 ab	9.71 cd
Centrosema acutifolium	2.17 bcd	0.93 bc	7.66 bc	6.69 ab	15.33 ab
Centrosema pubescens	1.04 d	1.34 bc	7.51 bc	5.60 bc	6.17 d
Mimosa invisa	1.97 cd	1.36 bc	7.49 bc	6.48 ab	13.33 bc
Desmodium ovalifolium	3.81 b	0.68 c	7.26 bc	6.78 ab	13.46 bc
Macroptilium atropurpureum	2.19 bcd	0.78 c	6.61 c	7.70 a	8.96 cd
Indigofera sp.	3.25 bc	1.27 bc	3.05 d	6.36 ab	8.50 c
F-test	**	**	**	*	**

[1] Cassava received 25 kg N, 25 P_2O_5 and 25 K_2O/ha; data for 1989 and 1990 refer to those plots with tractor preparation of cassava planting strips.
[2] at 10 months after planting.
[3] at 3 months; average of mechanical and chemical land preparation treatments.

A similar experiment was conducted in an adjacent field. In main plots two cassava plant spacings were used, i.e. 1.0 x 1.0 m and 1.50 x 0.67 m, both giving a plant population of 10,000 plants/ha. In subplots various forage species were planted in between cassava rows. Cassava received 156 kg/ha of 15-15-15 fertiliser. After the first cassava harvest, the cover crops were slashed back and cassava was replanted in 60-cm wide strips prepared with a hand tractor. In the second year all cover crops were well established and competed strongly with cassava, mainly for soil moisture during cassava establishment. Table 8 shows that there were no significant differences in cassava yields due to plant spacing, but that nearly all cover crops reduced cassava yields, some more than 50%. Most competitive were *Indigofera* and *Mimosa* sp. which were also among the most productive forage species tested. Less productive and thus less competitive were *Zornia glabra*, *Alysicarpus vaginales* and *Arachis pintoi,* although the latter still caused a marked yield reduction in the second year.

From these two cover crop experiments it can be concluded that cassava is a weak competitor and yields are reduced markedly if the plants have to compete with deep rooted and well established forage legumes used as a cover crop. This competition is particularly strong during cassava plant establishment, especially when this coincides with a period of drought. Thus, cover cropping with most forage legumes would not be practical since it tends to reduce cassava yields and requires considerable additional labour. Ruppenthal (1995) and Ruppenthal et al. (1997) showed that cover crops, once well established, were effective in reducing soil erosion in cassava fields in two locations in Colombia, but that erosion can be controlled more effectively and with less reduction of cassava yield with the use of contour hedgerows of vetiver grass (*Vetiveria zizanioides*).

Table 8. Dry matter production of various cover crops and their effect on the yield of cassava, cv. Rayong 1, planted at either 1.0x1.0m or at 1.5x0.67m at Pluak Daeng, Thailand. Data are average values for the two plant spacings.

	DM cover crops (t/ha)		Fresh cassava root yield (t/ha)	
Cover crop treatments	**1991/92**	**1992/93**	**1991/92**	**1992/93**
No cover crop	-	-	18.61 a	7.14 a
Indigofera sp.	6.55	3.15	8.33 c	4.19 abc
Zornia latifolia 9199	1.08	1.14	16.34 ab	3.94 bc
Zornia glabra 8283	0.47	1.68	22.23 a	5.44 ab
Alysicarpus vaginales	1.37	0.27	17.19 ab	6.70 ab
Mimosa invisa	4.61	2.96	12.71 bc	2.15 c
Stylosanthes hamata	3.21	5.23	13.61 bc	2.12 c
Arachis pintoi	0.26	0.42	15.97 b	2.30 c
F-test for cassava spacing (S)			NS	NS
Cover crops (C)			**	**
S x C			NS	*

The use of leguminous tree species in alley cropping to improve soil fertility

Growing crops between contour hedgerows of leguminous trees is called alley cropping, and is another alternative to improve soil fertility and reduce erosion. The space between hedgerows can be varied, but is usually around 4-5 meters, so that less than 20% of total land area is occupied by the hedgerows. The hedgerows are pruned before and at regular intervals after planting the crop and the pruning are distributed among crop plants to serve as a mulch, to supply nutrients (especially N), and to control weeds and erosion.

Adaptation of leguminous shrubs and tree species to conditions in Rayong, Thailand

Various leguminous shrubs were tested in Rayong, Thailand, to determine their general adaptation, ease of establishment, productivity of leaf/stem biomass, resistance to regular pruning and drought tolerance.

Table 9 shows that several species of *Sesbania* were highly productive in the first year, but did not resist regular pruning. Perennial pigeon pea varieties were easy to establish, were highly productive and drought tolerant, but they will last only a few years. *Leucaena leucocephala, Gliricidia sepium* and *Cassia siamea* were more difficult and slow to establish, but once established they were highly productive, resistant to pruning and very persistent. *Cassia siamea* is a non-N-fixing legume tree and serves mainly to produce biomass as mulch, to recycle nutrients and protect the soil from erosion. This species was also found to be particularly tolerant of acid soils (Howeler et al. 1999). Other species like *Flemingia macrophylla* and *Tephrosia candida* have been used successfully in other countries.

Some farmers in northern Thailand adopt hedgerows consisting of a mixture of fast-growing pigeon pea with a slower growing but more persistent tree species like *Leucaena leucocephala* (Boonchee et al. 1997).

Table 9. Total dry weight of pruning at three harvests as well as total nutrient content of the pruning of alley crop hedgerow species grown at Rayong Field Crops Research Centre, Rayong, Thailand in 1990/91.

Alley crop hedgerow species	Total dry matter (t/ha) Months after planting			Total nutrient content[1] (kg/ha)		
	3	6	13.5	N	P	K
Leucaena leucocephala	0	0.6	12.0	-	-	-
Gliricidia sepium	0.1	0.02	0.7	20	2	28
Cassia siamea	0.2	1.2	25.4	526	37	668
Sesbania grandiflora	1.1	0.4	0.3	49	3	51
Sesbania sesban	3.0	2.5	0	79	8	116
Sesbania aculeata	4.8	1.3	0.4	130	12	126
Sesbania javanica	1.6	0.7	0.4	53	4	52
Sesbania rostrata	3.7	1.2	0	77	5	73
Pigeon pea from USA	2.3	3.7	15.0	388	26	480
Pigeon pea ICP 8094	3.7	2.7	12.4	345	23	403
Pigeon pea ICP 8860	3.6	4.6	14.6	384	28	527
Pigeon pea ICP 11890	4.0	3.2	21.0	517	33	565

[1] Sum of nutrients in leaves and stems from 3 harvests.

Alley cropping of cassava with leguminous shrubs in Malang, Indonesia

The use of hedgerows of *Flemingia macrophylla* and *Gliricidia sepium* in cassava fields were investigated for four years in Malang, Indonesia. The experiment had eight treatments without replication. Eroded soil was collected in concrete channels below each plot.

The two hedgerow species were initially difficult to establish and during the first three years they had no beneficial effect on cassava yield or erosion (Wargiono et al. 1998). However, in the fourth year, when cassava in other plots suffered from severe N-deficiency after intercropping with maize, the cassava plants in the alley-cropped treatments were tall and had dark green leaves, indicating that the pruning of the hedgerows had supplied considerable amounts of N. Table 10 indicates that during the fourth year the two alley-cropped treatments produced high cassava yields and had the lowest levels of erosion (by enhancing early canopy cover).

In a previous experiment in the same site, hedgerows of *Leucaena leucocephala* and *Gliricidia sepium* also produced the highest cassava yields and lowest levels of erosion during the fourth year of consecutive planting; these two treatments also resulted in the highest levels of soil organic matter , the lowest bulk density and the highest infiltration rates and soil aggregate stability (Wargiono et al. 1995). Table 10 also shows that cover cropping with *Mimosa* sp. reduced cassava yields only slightly in the first two years, but markedly in the subsequent two years.

Table 10. Effect of various crop/soil management practices on soil loss due to erosion and on cassava and maize yields during four consecutive cropping cycles on 5% slope in Jatikerto Experiment Station, Malang, Indonesia.

Crop/soil management treatments	Dry soil loss (t/ha)				Cassava yield (t/ha)				Maize yield (t/ha)		
	91/92	92/93	93/94	94/95	91/92	92/93	93/94	94/95	91/92	92/93	93/94
1. C+M[1)], no fertilisers, no ridges	58.3	49.3	55.7	8.5	16.3	15.8	5.1	6.6	-	-	0
2. C+M, no fertilisers, contour ridges	43.0	36.9	36.7	2.8	25.4	23.2	5.1	13.3	-	-	0
3. C+M, with fertilisers, contour ridges	39.2	24.8	28.1	3.8	20.4	20.5	17.8	16.7	1.98	2.27	2.88
4. C+M, with fertilisers, contour ridges, elephant grass hedgerows	36.9	19.8	20.8	2.4	18.4	17.4	11.8	19.3	1.36	1.42	1.96
5. C+M, with fertilisers, contour ridges, *Gliricidia* hedgerows	43.2	22.3	20.9	2.2	16.3	18.0	16.1	20.7	1.16	1.28	2.80
6. C+M, with fertilisers, contour ridges, *Flemingia* hedgerows	41.3	17.7	17.3	1.9	17.2	18.1	14.2	21.6	1.26	1.46	3.20
7. C+M, with fertilisers, contour ridges, *Mimosa* cover crop	38.4	18.3	24.7	2.4	17.1	18.2	12.2	9.9	1.44	1.63	3.36
8. C+M[1)], with fertilisers, contour ridges, peanut intercrop	36.4	21.7	26.3	4.5	23.7	23.7	19.9	25.3	-	-	2.10

[1] During the first two years there was no intercropped maize in treatments 1, 2 and 8 ; C+M= cassava intercropped with maize.

Thus, once well established, hedgerows of leguminous shrubs used for mulch significantly enhanced soil fertility and improved the soil's physical characteristics. However, in less fertile soils or in areas with a long dry season, hedgerows can severely compete with neighbouring cassava for water and nutrients (Jantawat et al. 1994); they also require additional labour to keep properly pruned to prevent light competition.

The use of grasses as contour hedgerows to reduce erosion on hillsides

Many researchers (Ruppenthal 1995; Ruppenthal et al. 1997; Vongkasem et al. 1998; Nguyen The Dang et al. 1998; Zhang et al. 1998) have shown that planting contour hedgerows of vetiver grass is a very effective way to reduce erosion when cassava is grown on hillsides. In farmer participatory research (FPR) trials in Vietnam and Thailand, farmers have consistently identified this as the most effective way of controlling erosion (Howeler et al. 1998). Nevertheless, few farmers have actually adopted the technology because vetiver grass can only be propagated vegetatively, planting material is often difficult to obtain, and transport and planting costs are high. Moreover, vetiver grass is not a good animal feed, the stems do not provide fuel wood, and the leaves do not add nitrogen to the soil. To overcome some of these problems, other grasses were evaluated for their ability to form a dense hedgerow that is effective in reducing erosion, without competing excessively with neighbouring cassava or spreading by seed or stolons into adjacent cropland.

Contour hedgerows of grass species for erosion control in Khaw Hin Sorn, Thailand

In 1996, cassava cv. Kasetsart 50, was planted along contour lines at a spacing of 1.0 x 1.0 m in plots of 7 x 10 m on a gentle slope (5-6%) in Khaw Hin Sorn. Fifteen grass species were tested as contour hedgerows by planting them between every third cassava row to give three hedgerows per plot. Treatments were not replicated. Eroded soil was trapped in a plastic-covered ditches along the bottom end of each plot. These eroded sediments were collected and weighed to determine soil loss due to erosion. Most grasses were planted vegetatively, but *Brachiaria ruziziensis, B. brizantha, Setaria sphacelata, Paspalum atratum* and *Panicum maximum* were planted from seed. Three accessions of vetiver grass were also included. Cassava was fertilised with 312 kg/ha of 15-15-15. All grasses established well in the first year. Hedgerows were cut back at a height of 30 cm 2-3 times a year, and the cut leaves were mulched between cassava plants. After 11 months, cassava plants were harvested row by row. The same plots were replanted with cassava in 1997 and 1998, while hedgerows were maintained by regular pruning.

Table 11 shows that in the first and second year cassava in check plots without hedgerows produced 19.6 and 21.5 t/ha of fresh roots, respectively. During the first year of establishment, some plots with grass hedgerows, i.e. *Paspalum atratum* and *Setaria sphacelata,* produced higher cassava yields than the check plot, but most other grasses, notably Napier (*Pennisetum purpureum*), *Brachiaria ruziziensis* and *Panicum maximum CIAT* 6299, competed strongly with neighbouring cassava plants, resulting in a marked reduction in yield.

Table 11. Effect of contour hedgerows of various grass species planted between every third cassava row on cassava root yield and soil erosion when grown on 5% slope in Khaw Hin Sorn, Thailand in 1996/97 and 1997/98.

Hedgerow treatments	Cassava fresh root yield (t/ha)		Dry soil loss (t/ha)	
	1996/97	1997/98	1996/97	1997/98
Control without hedgerows	19.6	21.5	3.6	3.7
Vetiver grass 'Nakorn Sawan'	15.7	6.8	3.3	2.9
Vetiver grass 'Sri Lanka'	16.9	8.2	4.3	1.6
Vetiver grass 'Songkhla 3'	19.6	6.5	4.0	3.4
Lemon grass	12.9	12.1	4.2	2.1
Citronella grass	13.7	8.8	2.7	2.0
Panicum maximum TD 58	13.3	7.1	9.0	14.8
Panicum maximum CIAT 6299	9.6	5.5	3.4	2.2
Paspalum atratum BRA 9610	33.0	14.8	3.1	2.1
Setaria sphacelata	22.1	7.8	3.4	3.1
Brachiaria brizantha	16.4	7.5	2.0	1.7
Brachiaria ruziziensis	9.0	5.9	2.0	2.1
Dwarf napier grass	5.1	4.6	2.9	1.7
Normal napier grass	2.4	0.2	5.2	1.8
King grass	10.7	1.4	7.7	3.8
Sugarcane (for chewing)	12.5	5.8	2.5	1.5

In the second year, cassava encountered drought during the establishment phase and suffered from strong competition for water from the neighbouring grass hedgerows of all species. Figure 1 shows that napier grass and King grass *Pennisetum* were particularly competitive, reducing cassava yields dramatically, not only in the neighbouring rows but also in the centre row, 1.5 meter away from the grass. Most other grasses affected the yield of cassava mainly in the neighbouring rows but not in the centre row. *Paspalum atratum* was again least competitive, followed by lemon grass (*Cymbopogon citratus*) and citronella grass (*Cymbopogon nardus* Rendle); the vetiver grasses were intermediately competitive. Soil erosion losses were relatively low and differences among the plots are probably not related to treatments.

During the third year, 1998/99, it was observed that all grasses seriously competed with cassava in neighbouring rows except for lemon and citronella grass and the vetiver grasses; the latter have a vertical root system that does not overlap with the rooting zone of cassava (Tscherning et al. 1995). *Paspalum atratum*, which did not compete much in the first two years, tended to expand somewhat laterally, causing more competition for light in the neighbouring cassava rows. Thus, while *Paspalum atratum* seems like an attractive option, as the grass makes an excellent animal feed and can be grown from seed as well as from vegetative planting material, in those areas where animal feed is not important to farmers, the best alternatives probably remain vetiver grass and lemon grass. The latter is an important ingredient in Thai cooking and thus has market value for the farmer.

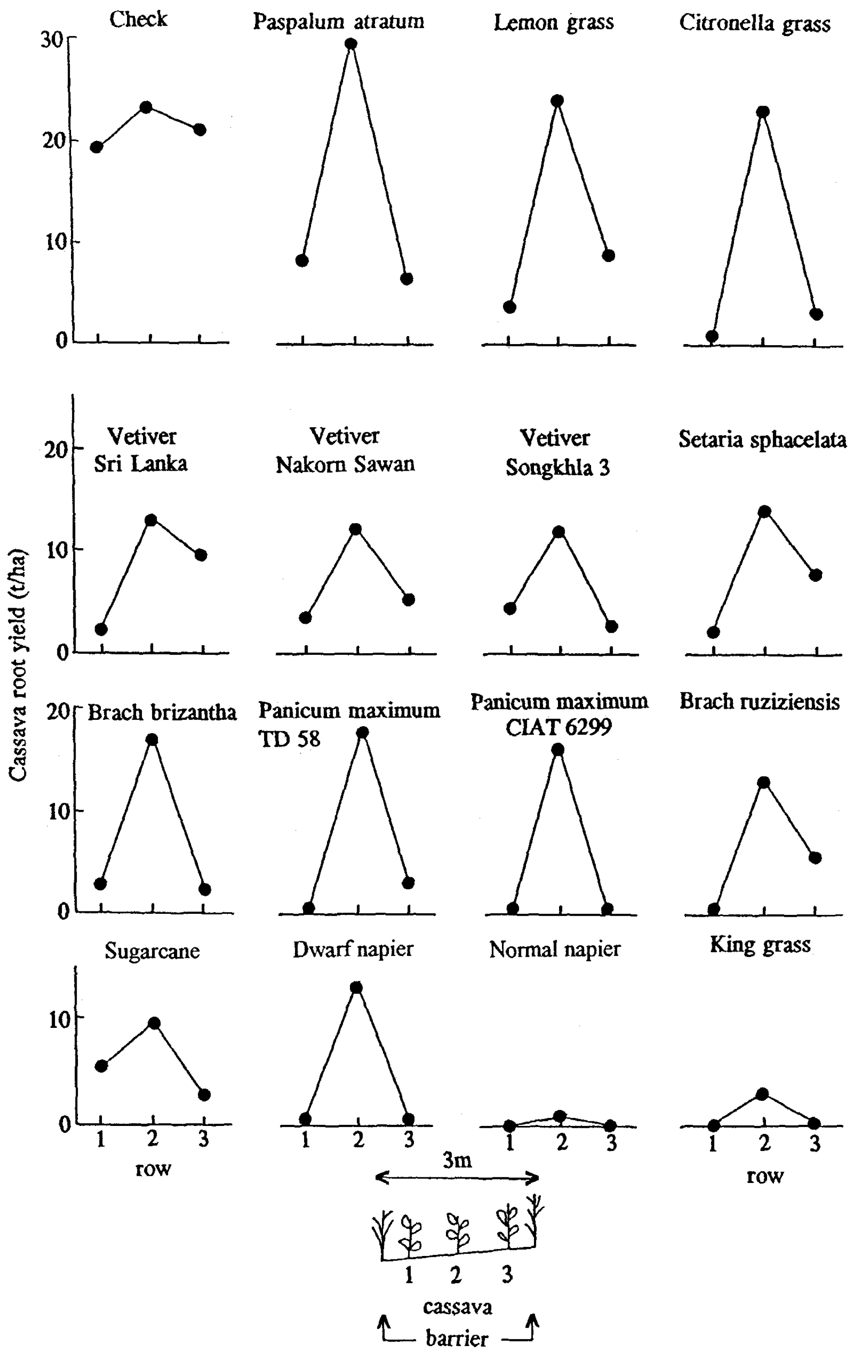

Fig. 1. **The effect of different grass species used as contour barriers on the fresh root yield of cassava, cv. KU 50, grown in three rows between barriers in Khaw Hin Sorn, Chachoengsao, Thailand in 1997/98.**

Summary and conclusions

Results from the experiments described above can be summarized as follows:

Intercropping and cover cropping – Cassava is a weak competitor and yields were seriously reduced when the crop had to compete with intercropped species, especially vigorously growing perennial species, like *Stylosanthes guianensis, S. hamata, Centrosema pubescens, Indigofera hursita, Mimosa* sp. and *Pueraria phaseoloides* or long-duration annuals like *Mucuna* sp. (velvet bean) pigeon pea or cowpea. However, intercropping with short-duration grain legumes, such as peanut, mungbean, soybean and erect types of cowpea, usually has little effect on cassava yield and provide farmers with additional income (Nguyen Huu Hy et al. 1995), protect the soil from erosion (Tongglum et al. 1992) and may improve fertility if crop residues are incorporated. Intercropping with peanut is commonly practiced in Vietnam, China and Indonesia, while intercropping with soybean or peanut is common on the calcareous soils of southern Java of Indonesia.

Green manuring – Growing a green manure crop before cassava and either incorporating or mulching of the crop residues before planting cassava generally improved soil fertility and increased cassava yields, especially in sandy and low fertility soils. In areas with intermediate soil pH, the most productive species were pigeon pea, *Indigofera hirsuta* and *Sesbania speciosa.* In soils of higher pH in Pluak Daeng, *Crotalaria juncea* was consistently the most productive and most effective specie in increasing cassava yields, followed by velvet bean and *Canavalia ensiformis.* However, in areas with only one relatively short wet season, green manuring may not be practical since the green manure is grown during much of the wet season, resulting in low cassava yields due to drought stress in the following dry season.

Alley cropping – Cassava is grown in strips (alleys) between single or double rows of perennial tree legumes; the legumes are cut back regularly and the leaves are mulched between cassava plants. *Cassia siamea* was found to be very productive, but there is little experience with the use of this species in alley cropping. In high pH soil in Indonesia alley cropping with *Leucaena leucocephala, Gliricidia sepium* and *Flemingia macrophylla* was found to be effective in increasing cassava yields and reducing erosion.

Grass hedgerows – These are planted along the contour in hilly areas, usually at 1-2 m vertical distance to reduce runoff and trap eroded sediments. The most effective species so far identified are vetiver grass, lemon grass, citronella and *Paspalum atratum.* The latter has the advantage of being a useful animal feed, while it can be propagated either from seed or from vegetative material, thus reducing the cost of establishment. Napier grass is commonly used as a hedgerow along contours or plot borders in Indonesia (Wargiono et al. 1995; 1998), where it does not seem nearly as vigorous and competitive as in Thailand (Jantawat et al. 1994), either due to more frequent cutting or because of a different ecotype used.

It may be concluded that forage legumes can play a role in improving soil fertility in cassava, mainly when used as a green manure before planting cassava or as a hedgerow (alley crop) between cassava, but whether or not it is practical depends on the rainfall distribution, availability of land and labour, as well as the cost and availability of alternative nutrient sources, like animal manures and chemical fertilisers.

Cover cropping with perennial forage legumes in cassava does not seem practical, as the legumes compete too strongly with cassava, especially for soil moisture during the early cassava establishment phase.

Alley cropping with hedgerows of leguminous tree species seem to increase cassava yields once the hedges are well established, but may decrease yields in the short-term by occupying a considerable portion of the land.

Contour hedgerows of grasses, such as vetiver and lemon grass, or *Paspalum atratum*, have been shown to be very effective in controlling erosion while not competing too strongly with neighbouring cassava plants. If the grass has some additional value, either through direct sale (lemon grass) or as animal feed, this will be an attractive option for farmers.

Thus, while forage species can play an important role in maintaining soil fertility and reducing erosion, the use of all these species has both advantages and disadvantages. Ultimately, farmers themselves have to decide whether any of these are useful under their particular conditions.

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