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PERFORMANCE OF TROPICAL FORAGES UNDER THE CLOSED CANOPY OF THE OIL PALM. II. LEGUMES

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Keywords: Tropical legumes, Oil palm, Cutting frequency, Light transmission

RINGKASAN

Satu percubaan telah dijalankan di bawah naungan pokok kelapa sawit dengan penembusan cahaya dari 15.8% ke 5.7% bagi menilai kesesuaian lapan jenis kekacang tropika dari segi prestasi agronomi, komposisi kimia, tumbuhan dan ketahanannya menerusi tiga peringkat pemotongan iaitu 4, 8 dan 12 bulan.

Kesemua kekacang didapati berkurangan hasilnya apabila pemotongan kerap dibuat iaitu dari 4 bulan ke 12 bulan kecuali *D. ovalifolium* yang menghasilkan berat kering dua kali ganda pada lapan bulan jika dibandingkan dengan pemotongan yang dibuat setiap empat bulan.

Kekacang *D. ovalifolium* dengan sifatnya yang lambat membesar dan kadar garam-galiannya yang rendah sebaliknya mempunyai berat akar serta bintil yang tinggi. Ia juga mempunyai permukaan daun yang lebar bagi menghasilkan berat kering yang tinggi (1 970 kg/ha/tahun) dan juga kandungan nitrogen yang tinggi (34 kg/ha/tahun).

Walaupun kekacang *C. caeruleum* dan *C. pubescens* terus menunjukkan penghasilan yang tinggi bagi kandungan garam-galiannya serta pertumbuhan yang cepat, masing-masing hanya dapat mencapai 29% dan 20% berat kering jika dibandingkan dengan *D. ovalifolium*. Kedua-dua spesies ini berupaya mengeluarkan akar yang banyak bagi menjamin pertumbuhan yang sederhana dan masing-masing mencapai 36.1% dan 38.3% pokok yang dapat hidup.

D. heterophyllum dan *Stylosanthes guianensis* cv. Endeavour dan cv. Cook, walaupun mempunyai ukuran daun yang lebih besar iaitu masing-masing dapat tumbuh 3.3, 2.6 dan 2.8 kali ganda dari biasa tetapi tidak memberi hasil yang memuaskan.

C. mucunoides dan *M. atropurpureum* cv. Siratro didapati pokoknya lebih cepat merosot apabila ditanam di kawasan yang kurang mendapat cahaya.

INTRODUCTION

There are about two million hectares of rubber, one million hectares of oil palm and 0.31 million hectares of coconut in the country. In the case of rubber there are 70%–80% interrow land available for cultivation (ANI AROPE, 1976); and if not cultivated, a high density of undergrowth comprising grasses and broad-leaf weeds could be found. The leguminous cover crops were first introduced to the rubber plantations for the purposes of weed suppression and water and soil conservation during the 1920's (WATSON, 1957). It was later looked into for the improvement of soil nitrogen (HAMILTON and PILLAY, 1941; WATSON, WONG and NARAYANAM, 1964; FOSTER, 1975; BROUGHTON, 1976; LIM and CHAI, 1976) and recently for the provision of extra income from pasture and livestock production (WAN MOHAMED 1977; CHEN, CHANG, AJIT and HASSAN WAHAB, 1978; DEVENDRA, 1978).

TAJUDDIN, ISMAIL, CHIN and PUSHPARAJAH,(1979) reviewed some of the latest findings on the contributions of leguminous covers in rubber and the extra benefit from the use of shade-tolerant legumes as well. They indicated, that, the identification of shade-tolerant legumes is very important either in the context of plantation crops or from the feed resources point of view.

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Some tropical legume species such as *Centrosema pubescens, Calopogonium mucunoides, C. caeruleum, Desmodium heterophyllum, D. ovalifolium, Macroptilium atropurpureum* cv. Siratro and *Stylosanthes guianensis* were reported to be shade-tolerant (LUDLOW, WILSON and HESLEHURST, 1974; JAVIER, 1974; STEEL and HUMPHRAYS 1974; GUZMAN and ALLO, 1975; WONG and WILSON, 1980) or well adapted to conditions under the plantation canopies (WATSON *et al.*, 1964; BROUGHTON, 1976; REYNOLDS, 1978; HAN and CHEW, 1981). However, these legumes were screened separately, in different environments with illumination ranging from 10% to 100% daylight. It will be of great advantage to understand the growth and production of these legumes under the plantation environment where light transmission is a critical factor.

The objective of the study was to screen eight tropical legumes for their general performance and their changes in dry matter yield, in chemical composition and in plant survival with time in response to different cutting frequencies under a fully closed canopy of the oil palm.

MATERIALS AND METHODS

General information regarding the oil palm and light transmission in relation to the experiment has already been described in the previous paper (CHEN and BONG JULITA, 1983). The mean light transmissions under the canopy as compared to that in the open at mid-day are summarised in *Table 1*.

In this experiment, a total of eight legumes were included in a split-plot design with species in the main plots (size: 4 m x 4 m) and cutting frequency (4, 8 and 12-months) in the subplots (size: 1.3 m x 4 m) in six replications. The eight species were:

Species	Common Name	Seed (g/plot)
1. *Calopogonium caeruleum*	–	35
2. *Calopogonium mucunoides*	–	20
3. *Centrosema pubescens*	Centro	50
4. *Desmodium heterophyllum*	Hetero	–
5. *Desmodium ovalifolium*	–	20
6. *Macroptilium atropurpureum* cv. Siratro	Siratro	40
7. *Stylosanthes guianensis* cv. Endeavour	Stylo Endeavour	20
8. *Stylosanthes guianensis* cv. Cook	Stylo Cook	20

Inoculated seeds were used for the initial sward establishment on December 15, 1975 except *D. heterophyllum* which was planted from rooted vegetative material.

Table 1. Percent light transmission during the day under the closed canopy of the oil palm

Time	Year I (August 1976)	Year II (September 1977)
7.00 am	2.5%	–
8.00 am	–	2.5%
9.00 am	21.1%	–
11.00 am	38.0%	10.7%
1.00 pm	16.7%	–
3.00 pm	14.1%	4.1%
5.00 pm	2.9%	–
Mean	15.8%	5.7%

Seeding rates of the various legumes as stated in the above table were worked out on the basis of their seed viabilities with the aim of achieving similar plant population per plot. Weekly germination counts were made until the 9th week after sowing on randomly placed quadrats (0.3 m x 0.3 m). A total of three quadrats per sub-plot were taken during seedling counts.

A general cut-back was made to all legumes on June 15, 1976 at heights between 5 to 10 cm so as to condition the species to an even vegetation at the start. Dry matter (DM) yields were recorded from cutting the sward in the whole plot where a small sample was taken for plant mineral composition analyses. Seed collection was made from the 12-month cutting treatment plots almost 10 months after the experiment started. It was observed that some pods of *C. mucunoides* had already shattered their seeds by then. A total of three collections of seed were made during the experiment. Leaves from three to five plants of each species in the main plots were randomly selected and removed for single leaf area measurement, using an area meter (LI–COR model 3100) on December 7, 1977. These plants were later dug up with the help of splashing water and spade to the depth of 25 cm and diameter of 20 cm, and oven-dried for root weight and nodulation records. Meanwhile, leaves from two plants of the same species/cultivars in the museum plot, approximately half a mile away from the experimental site were taken for leaf area measurements as the control. Before the above parameters were taken, plant number count in three random quadrats (0.3 m x 0.3 m) were recorded but data on the final number of plants that survived at the end of the experiment were not available because the experimental site was accidentally sprayed with weedicide during oil palm management.

Basal fertilizers were applied immediately after planting at a rate of 30 kg/ha of each P and K and subsequent maintenance fertilizers of 50 kg/ha/year of each P and K in the forms of triple super phosphate and muriate of potash, respectively. They were split equally in three applications annually and were applied after each harvest.

In order to understand the growth pattern of plants under the closed canopy of the oil palm, one plant from each of the selected legume species were grown in polybags in four replications on June 14, 1976. Top soil from outside the experimental site was used to fill the individual polybags. All seeds were inoculated with appropriate rhizobia before planting. After planting, hand watering was carried out every morning, except when it rained. The plants were harvested on the 12th-week after planting at 3-weeks interval. The whole plant was removed from the polybag, washed and oven dried for DM content and separated into leaf, stem, root and nodules.

RESULTS

Light measurements under the palm canopy, averaging from 15.8% daylight in year I to 5.7% daylight in year II showed that there was no statistical significant difference in any position of light measured at the fixed points during the day. It is assumed that uniform light distribution was ensured under the palm canopy during the course of the experiment. Rainfall recorded during the period did not produce any specific influence on the legume production *(Figure 3)*.

The overall plant growth of all the legume species during the early stage of the experiment was fairly vigorous except in Siratro which appeared very weak (etiolated) and suffered from foliar blight caused by *Rhizoctonia solani.* After one year, the growth of all legumes deteriorated rapidly except for *D. ovalifolium, C. caeruleum* and Centro which still showed green, vigorous and healthy plants. It was observed that all plants tended to be etiolated, particularly the Siratro and the two Stylos. Insect attack on Siratro and Hetero by *Lamprosema diemenalis* was noticed two months after the experiment. Seed collections were made from the following species: *C. mucunoides* (2 377 seeds/plot), *D. ovalifolium* (579 seeds/plot), Centro (434 seeds/plot) and Stylo Endeavour (41 seeds/plot).

Single plant growth in relation to sward

The growth of single plant at 32nd week, in polybags under the same canopy showed that *C. caeruleum*, Centro and *C. mucunoides* achieved faster establishment than Siratro and *D. ovalifolium* which in turn were better than Hetero. The two Stylos were slowest in establishment *(Table 5)*. Unlike other species, *D. ovalifolium* recorded a very slow rate of growth at the beginning. It gained its pace only after 23rd week from planting. The Hetero and Siratro grew fast initially, but they declined drastically after the 20th week *(Figure 1b)*. Similar results were recorded on root development for the various legumes *(Figure 1a)*.

All the legume species showed relatively good nodulation ranging from 8.5 to 15.1 nodules/plant except Stylo and Siratro which had only 4.2 and 2.3 nodules/plant, respectively. Efforts were made to relate the single plant growth characters of various legumes with those in the sward and it was found that single plant characters such as nodule, root DM and whole plant DM were positively correlated to root DM and plant survival in the sward as shown in *Table 2*.

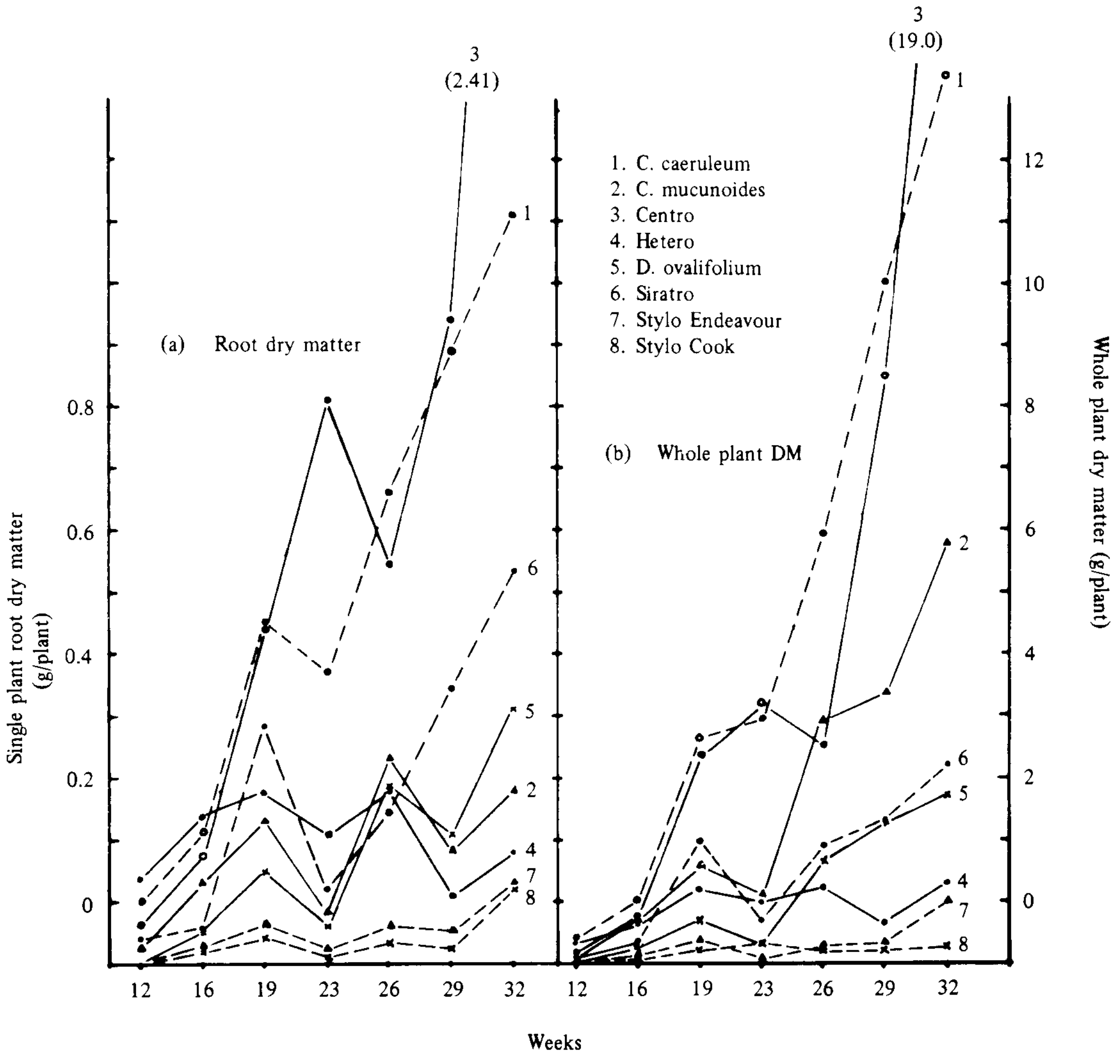

Figure 1: The single plant growth of various tropical legumes under the oil palm canopy.

Table 2. Correlation coefficients between characters of single plant and sward from the tropical legumes

Single plant character	Sward character	
	Root DM (g/plant)	% Survival*
Nodule	0.60	0.72
Root	0.42	0.38
Whole plant	0.55	0.47

*Species *C. mucunoides* excluded

Accumulated total dry matter yields of the legumes over the experimental period of two years ranged from as high as 1 950 kg/ha/year *(D. ovalifolium)* to as low as 74 kg/ha/year (Siratro) *(Tables 3* and *5)*.. All legumes responded markedly (P<0.01) to the cutting treatments when grown under the oil palm canopy *(Figure 3)*. Their DM decreased when cutting interval was increased from four months to 12 months with the exception of *D. ovalifolium* which increased yield by 96% *(Figure 2a)*. There were strong interactions (P<0.01) also between the species and cutting regime. *C. caeruleum* tended to maintain its yield under the same treatments. The DM yield also differed (P<0.01) between species *(Table 3)*, with *D. ovalifolium* ranking persistently higher (1 151−2 377 kg/ha/year) than *C. caeruleum* (550−700 kg/ha/year), Centro (351−468 kg/ha/year), Stylo Endeavour (267−337 kg/ha/year), *D. heterophyllum* (244−334 kg/ha/year), Stylo Cook (110−146 kg/ha/year), *C. mucunoides* (21−171 kg/ha/year) and Siratro (15−183 kg/ha/year).

Plant mineral composition

Under the critical light transmission situation found under the oil palm, all the mineral contents in the legumes were seriously affected. It was apparent that percentage nitrogen differed between species (P<0.01) ranging from 1.65% to 2.48% with mean nitrogen percentage in Centro (2.20% to 2.70%) being about 50% higher than the lowest viz. Stylo Cook (1.47% to 1.83%). The other legumes were ranked sequentially as *D. heterophylllyum* (2.08% to 2.27%), *C. caeruleum* (1.93% to 2.25%), *C. mucunoides* (1.73% to 2.04%), Stylo Endeavour (1.64% to 2.06%), *D. ovalifolium* (1.69% to 1.94%) and Siratro (1.85%). The overall nitrogen percentage declined significantly (P<0.01) when cutting interval increased from four months (2.13%), to eight months (1.91%) and to 12 months (1.79%) *(Figure 2c)*.

Under the 4-month cutting regime, the analyses showed that nitrogen concentrations of various legumes changed significantly with time. The nitrogen concentrations in Centro and *C. caeruleum* were the highest among the species studied and increased with time irrespective of their cutting frequency. The nitrogen concentration for the two *Desmodium* species plus *C. mucunoides* and Stylo Cook decreased with time under the 12-month cutting regime. The rest of the species tended to maintain the same level of nitrogen concentration at more frequent cutting intervals, i.e. 4 and 8-month. Total nitrogen production per hectare per year *(Table 5* and *Figure 2b)* was highest in *D. ovalifolium* (34 kg), following by *C. caeruleum* (12.7 kg), Centro (10.4 kg), Hetero (6.7 kg) and Stylo Endeavour (5.4 kg). The nitrogen productions of *C. mucunoides*, Stylo Cook and Siratro were 2.2 kg, 1.9 kg and 1.6 kg, respecitvely.

Of all the minerals tested, phosphorus was the only element with no significant differences between species *(Table 4)*. However, it decreased steadily (P<0.01) with time. Phosphorus levels in the legumes also decreased tremendously (P<0.01) from 0.21% at 4-month cutting to 0.13% at 8-

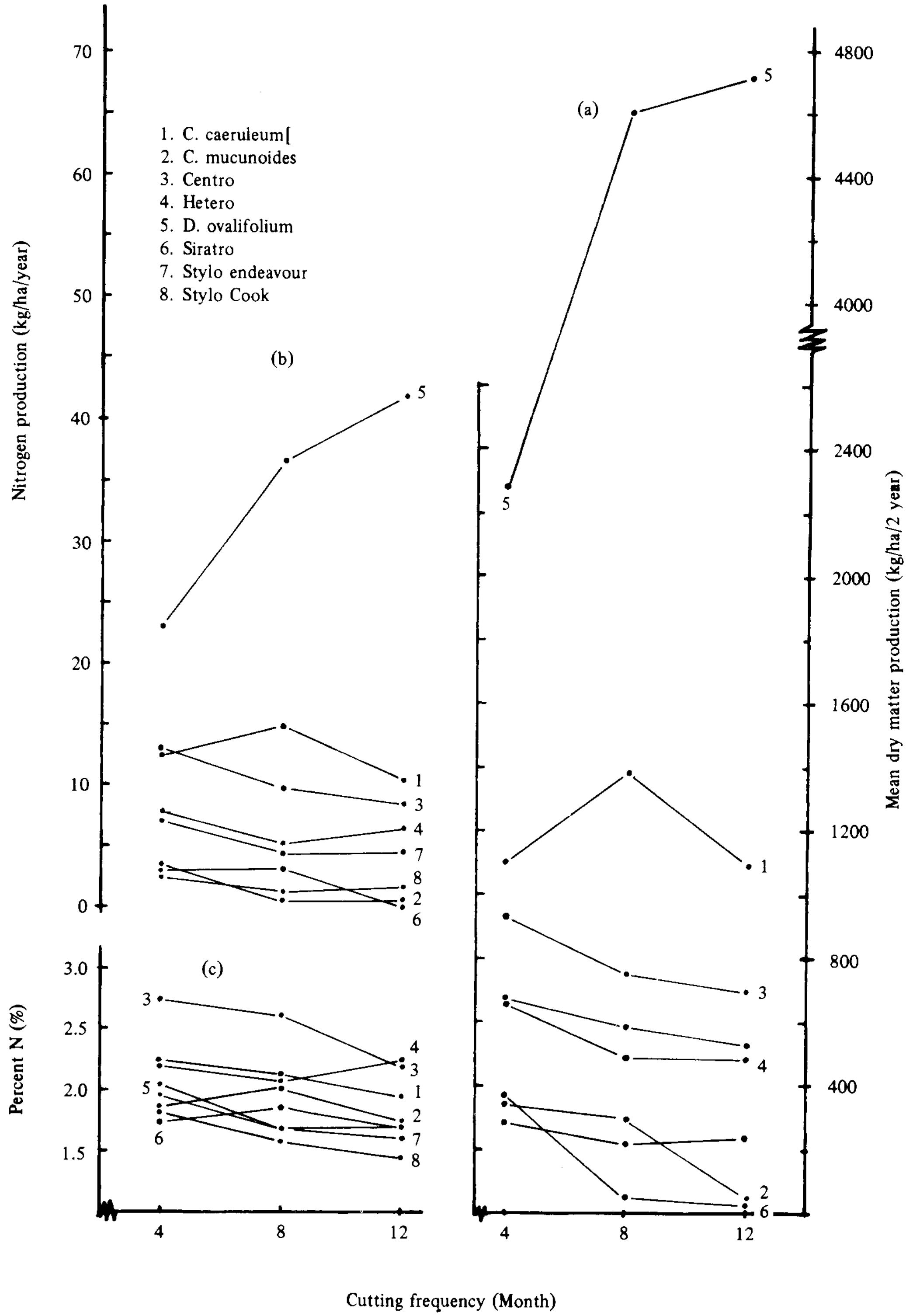

Figure 2. The nitrogen and dry matter production of tropical legumes in relation to cutting frequency under the oil palm

month cutting and to 0.13% at 12-month cutting in Year I, and from 0.15% to 0.13% and to 0.09%, respectively, in the following year when subjected to the different cutting frequencies. Phosphorus level in the two Stylos and *D. ovalifolium* appeared numerically lower than the rest of the species.

The potassium values were severely affected by cutting intervals declining by 13.2% at 8-month and by 40.8% at 12-month as compared to that of 4-month's. The highest values were found in the two Stylos (0.68% – 1.29%) and the lowest in *D. ovalifolium* (0.54% – 0.81%) and *C. mucunoides* (0.52% – 0.68%) *(Table 4)*. It was also observed that the decline of K values with time over two years was greatest with rates of 83%, 85% and 33% respectively for cutting frequency of 4, 8 and 12 months.

Unlike P and K, the calcium values in all the legumes increased consistently ($P<0.01$) with time, irrespective of their cutting intervals. The values varied ($P<0.01$) between species with *D. ovalifolium* (1.09% – 1.34%) and *C. caeruleum* (1.13% – 1.28%), being the highest, and Hetero (0.87% – 1.01%) the lowest.

Magnesium contents were significantly affected either between the cutting intervals or between species within each cutting interval over the time. The significant differences between species only at both 4-month

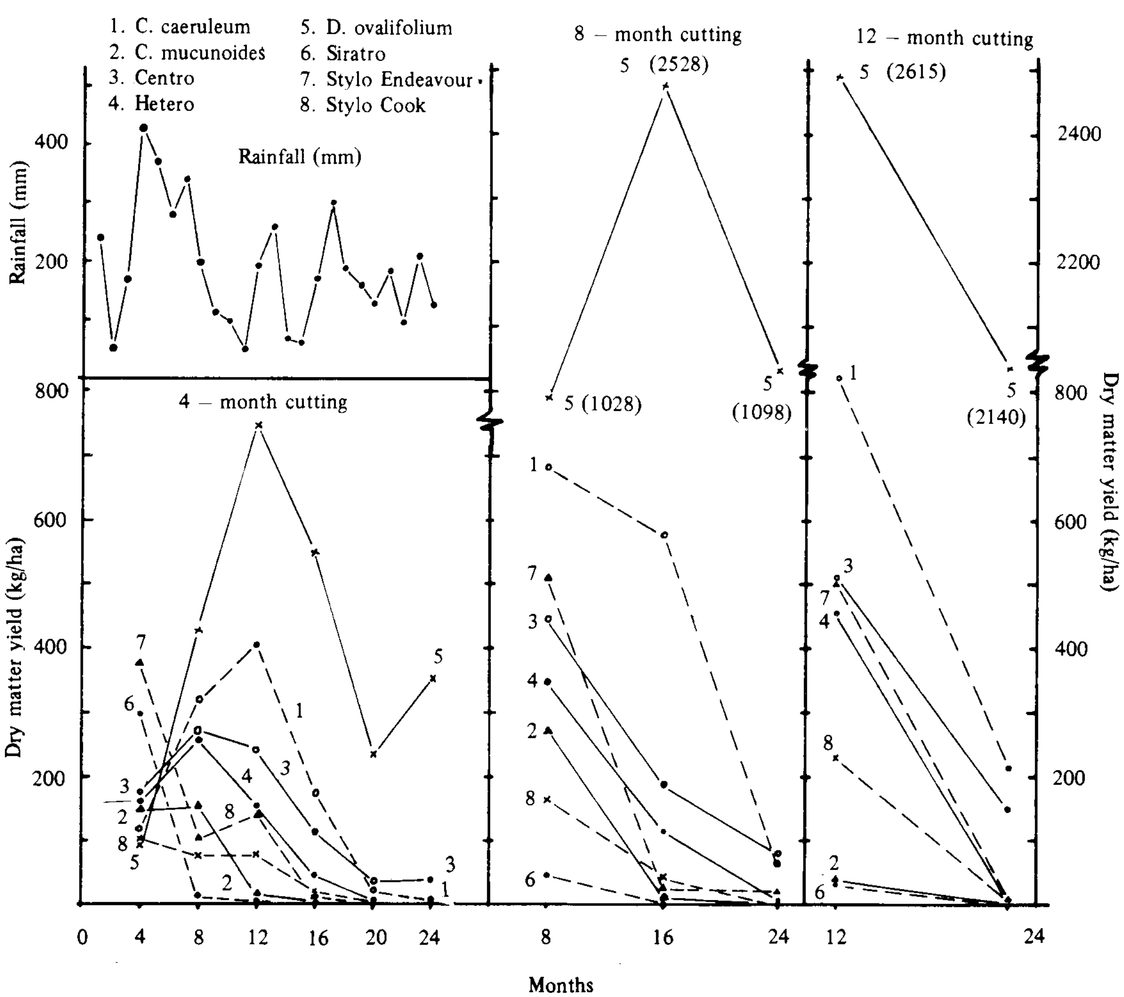

Figure 3. The effects of rainfall and cutting on changes in DM yield of tropical legumes.

Table 3. The effect of cutting frequency on total dry matter production of tropical legumes (kg/ha/2 years)

Treatment	Cutting frequency			Mean
	4 – month	8 – month	12 – month	
C. caeruleum	2.7536* (1113)	2.8391* (1400)	2.7145* (1100)	2.7691 (1205)
C. mucunoides	2.2321 (343)	2.1886 (300)	1.2817 (42)	1.9008 (229)
C. pubescens	2.4799 (936)	2.3347 (759)	2.3299 (702)	2.3815 (799)
D. heterophyllum	2.4546 (668)	2.3424 (498)	1.6827 (489)	2.1599 (552)
D. ovalifolium	3.0183 (2302)	3.3164 (4648)	3.3839 (4754)	3.2395 (3901)
M. atropurpureum cv. Siratro	2.2582 (366)	1.2605 (48)	0.7376 (31)	1.4188 (149)
S. guianensis cv. Endeavour	2.3307 (674)	2.2517 (587)	2.0812 (534)	2.2212 (598)
S. guianensis cv. Cook	2.1493 (293)	2.0097 (221)	2.0562 (242)	2.0717 (252)
Mean	2.4598 (762)	2.3179 (1058)	2.0335 (987)	
LSD value — Frequency	5% : 0.1613 1% : 0.2132	Species: 5% : 0.2634 1% : 0.3482	Frequency x species: 5% : 0.4564 1% : 0.4032	

*log x transformed
Parenthesis = actual data

Table 4. The changes in plant mineral composition of tropical legumes with time and its responses to cutting treatment under oil palm canopy

Treatment	4 – month cutting					8 – month cutting					12 – month cutting							
	N%	P%	K%	Ca%	Mg%	N%	P%	K%	Ca%	Mg%	N%	P%	K%	Ca%	Mg%	Mn	Cu ppm	Zn
D. ovalifolium	1.94	0.14	0.81	1.17	0.49	1.69	0.11	0.72	1.34	0.36	1.72	0.12	0.54	1.09	0.29	85.34	7.79	30.23
C. caeruleum	2.25	0.15	1.00	1.13	0.54	2.12	0.13	0.70	1.23	0.44	1.93	0.12	0.71	1.28	0.38	44.95	9.82	23.12
C. pubescens	2.70	0.15	1.02	0.93	0.43	2.54	0.13	0.92	1.01	0.30	2.20	0.11	0.47	1.05	0.30	44.95	11.85	23.95
S. guianensis cv. Endeavour	2.06	0.15	1.19	1.16	0.81	1.74	0.12	1.03	0.91	0.50	1.64	0.12	0.80	0.80	0.34	25.23	7.25	40.27
D. heterophyllum	2.27	0.15	0.96	0.91	0.50	2.08	0.13	0.96	0.87	0.42	2.10	0.11	0.61	1.01	0.31	53.46	11.45	29.54
S. guianensis cv. Cook	1.83	0.14	1.29	1.31	0.74	1.65	0.11	1.34	1.23	0.42	1.47	0.10	0.68	0.88	0.34	23.99	6.27	20.63
C. mucunoides	1.89	–	–	–	0.53	2.04	0.12	0.68	1.25	0.45	1.73	0.12	0.52	1.28	0.33	–	–	–
M. atropurpureum cv. Siratro	–	–	–	–	0.55	1.85	–	–	–	–	–	0.12	–	–	–	–	–	–
L S D	**	ns	**	**	**	ns	**	**	**	**	*	ns	ns	**	ns	**	*	ns
Harvest I	2.17	0.19	1.18	0.94	0.97	1.87	0.15	2.60	0.99	0.39	1.81	0.13	0.71	0.97	0.29	41.11	7.97	20.99
Harvest II	1.99	0.15	2.82	0.97	0.41	1.96	0.13	0.61	1.10	0,41	1,89	0.09	0.48	1.21	0.37	61.72	11.07	35.59
Harvest III	2.03	0.13	0.89	1.04	0.36	2.06	0.10	0.40	1.23	0.41	–	–	–	–	–	–	–	–
Harvest IV	2.26	0.15	0.68	1.23	0.47	–	–	–	–	–	–	–	–	–	–	–	–	–
Harvest V	2.19	0.10	0.48	1.33	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Harvest VI	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
L S D	*	**	**	**	**	ns	**	**	*	ns	ns	**	**	**	**	*	**	*

Table 5. The agronomic characters and performance of tropical legumes under oil palm canopy

Species	Single plant			DM (kg/ha)	N (kg/ha)	Nodule (No./plant)		Root dry weight (g/plant)		Leaf Area (cm²/leaf)		Plant number		
	Root (g/plant)	Mean nodule number (No/plant)	Whole plant DM (g/plant)							Open	Shade	Establishment (plant/ 0.27 m²)	Survival (plant/ 0.27 M²)	Survival %
D. ovalifolium	0.168	10.7	1.16	1970	34.0	1.96*	(101.3)	0.32**	(1.15)	8.5	11.3	67.5	27.8^{a}	41.2
C. caeruleum	0.614	15.1	5.97	570	12.7	1.20	(16.4)	0.32	(1.10)	42.7	32.0	13.2	4.7^{d}	35.6
C. pubescens	0.815	8.5	5.81	399	10.4	0.43	(3.2)	0.27	(0.92)	16.9	15.3	20.7	7.8^{d}	37.7
S. guianensis cv. Endeavour	0.054	8.7	0.33	300	5.4	1.41	(54.2)	0.11	(0.30)	1.2	3.3	91.5	14.5^{c}	15.8
D. *heterophyllum*	0.206	8.6	0.94	276	6.7	0.96	(9.8)	0.03	(0.08)	1.4	4.6	49.0	14.4^{c}	29.3
S. guianensis cv. Cook	0.039	4.2	0.21	126	1.9	1.01	(11.0)	0.12	(0.67)	0.9	2.7	71.2	17.7^{c}	24.9
C. mucunoides	0.182	10.5	2.68	114	2.2	0.68	(4.8)	0.17	(0.51)	52.6	15.8	18.2	22.1^{b}	121.4
M. atropurpureum cv. Siratro	0.323	2.3	1.52	74	1.6	0.03	(1.1)	0.04	(0.09)	9.3	6.0	69.7	3.4^{d}	4.8
L S D 5%						0.67		0.12		5.29				
L S D 1%						0.93		0.17		7.03				

*Log x transformed; **Log (x+1) transformed; Parenthesis – actual data
a, b, c, d = means with different superscripts in the same column are significantly different from each other ($P<0.05$).

and 8-month but not at 12-month. The two Stylos sustained the highes Mg values, whereas *D. ovalifolium* and Centro maintained the lowest.

The chemical values of manganese, copper and zinc were not available except at the 12-month cutting. All these elements increased in concentration with time from 41.1 ppm, 7.9 ppm and 20.9 ppm to 61.7 ppm, 11.1 ppm and 35.6 ppm respectively for Mn, Cu and Zn *(Table 4)*. There were significant differences between species in both manganese ($P<0.01$) and copper ($P<0.05$) but not in zinc. *D. ovalifolium* recorded the highest Mn (85 ppm) contents, while Stylo Endeavour had the highest Zn (40 ppm) and Centro the highest Cu content (11.8 ppm).

Leaf area, nodulation and plant root weight of the sward

Analyses of leaf area showed that individual leaf size of the legumes were significantly affected ($P<0.01$) by the shade of the oil palm canopy, with a mean value of 16.69 cm^2/leaf in the open and 11.38 cm^2/leaf in the shade. The species variations ($P<0.01$) ranged from mean values 37.35 cm^2/leaf in *C. caeruleum* to 1.82 cm^2/leaf in Stylo Cook. It was interesting to note that there were significant differences ($P<0.01$) in the interaction between species and shading *(Table 5)*. Some species, such as the two *Desmodiums* and two Stylos increased their leaf areas under shade as compared to that in the open; whereas the two *Calopogoniums*, Centro and Siratro recorded opposite effects. Under the shady canopy, *D. ovalifolium* experienced a 33% increase in leaf area, while Hetero, Stylo Cook and Endeavour recorded leaf sizes which were 3.3, 2.8 and 2.6 times respectively larger than normal. Of all the species tested, however, only the two *Calopogoniums* produced significant decreases from 42.70 to 32.02 cm^2/leaf for *C. caeruleum* and from 52.62 to 15.86 cm^2/leaf for *C. mucunoides*.

The formation of nodules by the end of the experiment varied significantly ($P<0.01$) between species with *D. ovalifolium* ranking first followed by Stylo Endeavour, *C. caeruleum*, Stylo Cook, Hetero, *C. mucunoides*, Centro and Siratro. Nodules of all the species examined were found to be relatively smaller in size and lighter in colour than the normal pinkish nodule. Root dry matter studies showed that there were highly significant differences between species, with *D. ovalifolium*, *C. caeruleum* and Centro ranking among the highest *(Table 5)*; while Siratro and Hetero ranked the lowest.

There were positive relationships between sward root weight and its nodulation and total pasture DM. The correlation coefficients of sward root weight and nodule number to total pasture DM were $r = 0.65$ and $r = 0.89$, respectively.

Plant survival

Under a shady environment, there was no significant cutting effect on number of plants that survived. However, there was much variation ($P<0.01$) between the species. The most persistent species was *D, ovalifolium* with a survival of 27 plants/-0.27m^2 equivalent to 41.2% of the initial plant population. It was significantly higher than the two Stylo (14.5–17.7 plants/0.27 m^2) and Hetero (14.4 plants/0.27 m^2). Although *C. caeruleum* (4.7 plants/0.27 m^2) and Centro (7.9 plants/0.27 m^2), had significantly lower plant numbers, they maintained the second highest survival rates of 36% and 38%, respectively *(Table 5)*. *C. mucunoides* was the only species with 21% increase in plant number.

In an attempt to correlate the sward root weight and nodule number to the percentage of plant survival, it was found that there were strong correlations between root dry weight and plant survival ($r = 0.80$) and between nodule number and plant survival ($r = 0.38$). In these analyses the species *C. mucunoides* was excluded from the computation since it did not reflect the mean treatment effect.

DISCUSSION

It is interesting to note that all the selected legumes in this experiment established easily and sustained different growth patterns under such a closed canopy with a low illumination of 15.8%–5.7% daylight *(Table 1)*. The positive correlations between plant characters of various legumes in single plant and in sward *(Table 2)* indicate that fast establishing species as single plants, such as *C. caeruleum* and Centro which had good root development and nodule formation, would probably perform and persist better in sward conditions; whereas slow growing species such as Siratro, Hetero and the two Stylos did not do well in the sward under shade *(Table 5)*. However, *D. ovalifolium* was an exception. It appeared slow and late in establishment *(Figure 1)* but performed the best among all the legumes with superior root development and highest nodule formation, sustaining 41.2% survival and produced the highest DM yield.

The overall production of dry matter of the eight legumes in this experiment under the palm canopy was low *(Table 3)* and declined drastically over time *(Figure 3)* despite the good initial plant establishment *(Figure 1)*. This is in agreement with results obtained by other workers (BURTON, JACKSON and KNOX, 1959; LUDLOW,, *et al.*, 1974; RAJARATNAM and CHAN, 1976) that shading reduced biomass and cumulative DM of tropical legumes. Although the DM yields of these legumes in the open were not measured in this experiment, their production in full sunlight per hectare per year had been reported (WONG, CHEN and AJIT, 1982) to be about 4.74 tons for *D. ovalifolium*, 5.27 tons for C. caeruleum, 5.07 tons for *C. mucunoides*, 8.69 tons for Centro, 2.74 tons for Hetero, 3.87 tons for Siratro, 4.85 tons for Stylo Endeavour and 6.35 tons for Stylo Cook. Based on these figures, the relative DM yield reduction at 15.8% daylight (Year I) and 5.7% daylight (Year II) were estimated to range from 60% to almost 100% between species. The best species, *D. ovalifolium*, could maintain about 40% of its relative yield in the open; whereas the second ranking species, *C. caeruleum* and Centro sustained only 10% and 15% of their relative yields, respectively. The remaining species produced negligible yields under such a low light environment. ERIKSEN and WHITNEY (1980) reported, however, that Centro when grown at 27% daylight could achieve 44% of its relative DM yield. The poor growth of Siratro and Stylo were also mentioned in the same report with relative DM yields of 20% and 10%, respectively. Even under the controlled environment at 10% daylight, Siratro produced about 10% of its relative DM yield (LUDLOW *et al.*, 1974), but at higher light levels (40% daylight) it could produce 60%–70% of its potential yield (WONG and WILSON, 1980).

Although there were marked responses in the legume species to cutting and strong interactions between species and cutting treatment *(Table 3* and *Figure 2a)*, *D. ovalifolium* showed outstanding performance among all. It also performed better when the cutting interval was prolonged to about eight months. Other species either declined in DM yield *(Figure 2)* or were not responsive to cutting frequencies of 4, 8 and 12-month *(Table 3)*. Indications are strong that when light is a critical factor in such an instance, the cutting frequency imposed may not be that important a factor in DM yield in most of the species *(Table 3)*.

Under the critically low light transmission situation, most mineral contents in the legumes were found to be relatively low *(Table 4)* and declined with time as compared to the results obtained by others in the open (ENG, KERRIDGE and MANNETJE, 1978; THAM and KERRIDGE, 1982) and in the shade (CHEN *et al.*, 1978; ERIKSEN, and WHITNEY, 1980). Low nitrogen percentage (1.47%–2.07%) in the plant and total nitrogen production as well *(Figures 2b, 2c)* are believed to be due to the deleterious effects of defoliation and shading on nodulation as reported for tropical pasture legumes (WHITEMAN and LULHAM, 1970).

The plant phosphorus concentration was far below the minimum level of 0.16%–0.23% for normal growth of legumes (ANDREW and ROBINS, 1969a; BRUCE, 1974). The potassium status declined with time and sustained a value below the critical point of approximately 0.8%, a value worked out by ANDREW and ROBINS (1969b) for a number of tropical legumes. Although it was evident that the calcium level for legumes increased with time *(Table 4)*, it was only sufficient for growth in legumes (0.55% – 1.00%) as stated by SHORROCKS (1964). ANDREW and NORRIS (1961) identified that Ca levels of 1.35% – 1.58% were associated with maximum yields of Centro and Stylo. However, based on the estimates by LONERAGAM and SNOWBALL (1969) for several legumes, the Ca levels recorded here were all below the functional requirement of 0.2 percent.

The magnesium level was quite high as compared to the results obtained by THAM and KERRIDGE (1982) for legumes grown on various soil types in Peninsular Malaysia, while the amount of copper was just above the marginal level of 5 ppm (ANDREW and THORNE, 1962).

In view of the low plant mineral status throughout the trial, it is evident that the critical low light intensity under the palm canopy has actually limited the uptake and fixation of nitrogen which in turn restricted the absorption of other minerals or vice versa. Similar findings in nitrogen uptake by Bermuda grass (BURTON, *et al.*, 1959) have shown that at 29% daylight, a relatively higher DM yield of 53% was obtained at 225 kg N/ha than of 29% at 1,796 kg N/ha. Further, ANDREW and ROBINS (1969b) reported good correlations between N and P concentrations in plant tops for 10 tropical legumes. The nitrogen concentrations in the plant tops were increased by phosphorus supply. Although, in this study, there were species differences in almost all mineral contents except phosphorus *(Table 4)*, it was rather difficult to identify and account for the performance of species under the canopy, as shade could be an overriding factor. STEEL and HUMPHRAYS (1974) reported that pasture growth, soil moisture and light transmission were not affected by proximity to coconut palms, but phosphorus was the main nutrient deficiency in the 0–30 cm horizon. There were no lateral gradient of root distribution from the palms and the pasture legume roots occupied the same region (to a depth of 95 cm) as the coconut roots. Therefore, the low mineral status in the plant tops and their sharp decline over time could also be attributed to the competition for nutrients by the oil palm roots.

Leaf area is one of the major attributes of plant growth and DM production (DONALD, 1961; RHODES, 1973). The changes in leaf size recorded for various legumes in this experiment *(Table 5)* showed the ability of each species to adjust their leaf size for maximum light interception under the palm canopy in order to achieve maximum growth and high productivity. The detection of positive correlations between the different agronomic characters would provide better identification for species that perform well under shade. *D. ovalifolium* was able to increase its leaf area by 33% in order to maximize its photosynthetic intake for growth. Although it was characterized by the lowest mineral contents throughout the trial *(Table 4)*, it was able to develop the best sward, rooting system and highest number of nodules *(Table 5)* which in turn gave it the most sigificant survival rate (41.2%) and DM (1 970 kg/ha/year) and nitrogen (34 kg/ha/year) production.

Although *D. heterophyllum* and the two Stylos were able to secure larger leaf sizes to cope with the low light intensity environment, they were retarded either by poor rooting system or fewer nodules. *C. caeruleum* experienced a 25% reduction in leaf size, but with the capability of developing one of the best rooting systems and having moderate nodulation per plant, it maintained the second highest DM yield production and had a survival rate of 36% of its initial plant population. The leaf area reduction in Centro was insignificant in contributing to the present performance probably because of the good rooting system which gave it the second highest survival rate (38%). Both the species, *C. caeruleum* and Centro, had the highest plant nitrogen concentrations during the trial *(Table 4)*.

C. mucunoides was a fairly good starter during establishment *(Figure 1)* but with poor rooting and nodulation, the species was fast deteriorating. Moreover, the plant tended to flower and set seed frequently which could weaken the overall vegetative performance under shade. The increasing plant population *(Table 5)* recorded towards the end of the trial, could be due to germinating seeds which dropped at the early stage of the experiment. Siratro showed the worst deterioration under the palm canopy *(Table 5* and *Figure 3)* despite initial good establishment *(Figure 1)*.

Agronomic Implications

The experiment was conducted under an extremely low light intensity environment with the oil palm age of about 5–7 years old. It is not surprising to note that all the legumes species did not perform as well as in the open. Based on the present results, the best species, *D. ovalifolium* could only produce approximately 40% of its potential yield in the open while the second ranking species, *C. caeruleum* and Centro could sustain only 29% and 20% of *D. ovalifolium* production. Results indicate clearly that at the moment none of the other legumes studied could grow better than *D. ovalifolium* under such an oil palm canopy. However, it is generally believed that these species should perform better if grown under younger oil palm where higher light intensity prevails. Therefore, the production and changes of the swards, their stabilities and adaptabilities in mixtures under grazing, in relation to various ages of the tree crops will deserve priority in future studies.

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SUMMARY

Under the closed canopy of the oil palm with mean light transmissions of 15.8% to 5.7% daylight, eight tropical legumes were evaluated for their general agronomic performance, plant chemical composition and persistence with three cutting frequencies of 4, 8 and 12 months.

All legumes declined in yield when cutting frequency was relaxed from 4 to 12 months except *D. ovalifolium* which increased by almost double in DM yield when cut at 8-month as compared to 4-month cutting.

D. ovalifolium which was characterised by slow plant establishment and low plant mineral status had the highest root weight, nodules per plant and bigger leaf area to produce the highest DM yield (1 970 kg/ha/year) and nitrogen content (34 kg/ha/year).

Although showing constantly higher plant mineral contents and fast plant establishment, *C. caeruleum* and *C. pubescens*, achieved only 29% and 20% DM, respectively, compared to *D. ovalifolium*. Both species were able to establish good root weight to sustain moderate growth and to achieve plant survival of 36.1% and 38.3%, respectively.

Although *D. heterophyllum* and *Stylosanthes guianensis* cv. Endeavour and Cook recorded larger leaf sizes ranging from 3.3, 2.6 and 2.8 times more than the normal, they produced negligible yields.

C. mucunoides and *M. atropurpureum* cv. Siratro deteriorated immediately after sward establishment under critical light environment.

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