Growth and N Fixation of Some Tropical Forage Legumes as Influenced by Solar Radiation Regimes[1]

F. I. Eriksen and A. S. Whitney[2]

ABSTRACT

Decreased solar radiation due to cloud cover or shading by plantation crops or associatedass can severely limit the production of tropical forage legumes. We therefore evaluated the response of six legumes (three replicated and three not replicated) to four radiation regimes (100, 70, 45, and 27% of unshaded solar radiation, hereafter termed "full sun") with polypropylene netting in the field.

The three replicated legumes had significant yield reductions at 27% full sun, with intermediate reductions at 70 and 45%. Dry matter (DM) yields at full sun [metric tons (mt) $ha^{-1}yr^{-1}$ and proportional yields at 27%] were: *Desmodium intortum cv.* Greenleaf (20.0, 46%); *Centrosema pubescens* 'centro' (13.7, 44%); and *Macroptilium atropurpureum cv.* Siratro (12.9, 20%). Greenleaf was relatively tolerant of moderate shading; proportional yields at 70 and 45% of full sun were 93 and 75%, respectively. Centro and Siratro yields declined linearly as shortwave radiation (hereafter termed "radiation") decreased, but Siratro yields declined significantly more than Centro. Marked seasonal differences were noted in the response of the legumes to shade, and this was attributed to differences in the ability of the legumes to utilize solar radiation during periods of cool temperatures. The three non-replicated legumes were evaluated similarly, except that yields were adjusted for replication effects. Dry matter yields and proportional yields at 27% full sun were: *Leucaena leucocephala* cv. Hawaiian Giant (23.5, 40 %); *Stylosanthes guianensis cv* gr. Schofield (17.0, 17%); and *Desmodium canum* `kaimi clover' (12.2, 32%). Hawaiian Giant and Greenleaf yielded similarly at 45 and 27% full sun. Kaimi clover DM yield tended to be slightly higher (13.8) at 70% full sun, but thereafter yields declined linearly with reduced radiation. Schofield stylo was the most sensitive to shading.

Dry matter and N concentrations were not significantly elevated by reduced radiation or cool weather except that N increased during the cool season. Concentrations of N differed among species being highest for centro and Hawaiian Giant (3.4%) and lowest for kaimi clover (2.6%). Total N yields were associated with DM yields. Nitrogen yields (kg N $ha^{-1}yr^{-1}$) of replicated legumes at full sun and proportional yields at 27% full sun were: Greenleaf (540, 45%), centro (461, 44%), and Siratro (362, 27%); and for the non-replicated legumes, Hawaiian Giant (751, 38%), Schofield (4%,18%), and kaimi clover [340 (361 at 70% full sun), 38%]. Acetylene reduction rates by nodules in soil cores were highly correlated with radiation regimes (r = 0.92-0.995; except for centro, r = 0.71.) Correlation of acetylene reduction rates with DM yields ranged from 0.80 to 0.996.

The higher yielding legumes, Greenleaf, centro, and Hawaiian Giant (plus kaimi clover for ≈70% full sun only) appear well-suited for areas of low solar radiation because they have relatively constant concentrations of DM and N and fixed significant quantities of N even under dense shade.

Additional index words: **Legumes, Solar radiation, Shading, Acetylene reduction, plant height, Nitrogen fixation, Nitrogen yield, Dry matter content, *Desmodium canum, Desmodium intortum, Centrosema pubescens, Leucaena leucocephala, Macroptilium atropurpureum, Stylosanthes guianensis.***

SOLAR radiation is usually high in the tropics and is often the least variable component of year to year differences in climate (Coaldrake, 1964). However, radiation varies with locations, seasons, and days depending on cloud cover. In forage grass-legume communities, competition for light between grasses and legumes is often an important factor influencing yields and stand composition (Santhirasegaram et al., 1966). There is excellent rationale for growing improved legumes and grass-legume mixtures under coconut palms and other plantation crops to suppress weeds, improve soil fertility and provide extra income from livestock (Hugh, 1972; Javier, 1974). Thus, tolerance of tropical legumes to reduced radiation can be important in their ability to produce and persist in competition with other plants.

Moderate to heavy shading reduced yields of Greenleaf desmodium *[Desmodium intortum* (Mill.) Urb.] and centro *(Centrosema pubescens* Benth.), but yield reductions were less than for Siratro *[Macroptilium atropurpureum (D.C.)* Urb.] and stylo *(Stylosanthes guianensis* Swartz) (Ranacou, 1972). Poor growth of Siratro at reduced radiation has also been reported by Ludlow et al. (1974).

Yields of Greenleaf desmodium previously recorded have ranged from 10 to 21 metric tons (mt) $ha^{-1}yr^{-1}$ (Olsen and Moe, 1971; Plucknett and Fox, 1965; Whitney et al., 1967; Whitney and Green, 1969; and Younge et al., 1964). In Malaysia, yields of stylo, centro, and Siratro in mixtures with grass were less than 16 mt $ha^{-1}yr^{-1}$ (Ng and Wong, 1976).

Date (1973) estimated the N fixed by tropical forage legumes in grass association to be in the range from 100 to 200 kg N $ha^{-1}yr^{-1}$. In Hawaii *Desmodium spp.* grown alone and with grasses fixed between 47 and 407 kg N $ha^{-1}yr^{-1}$ (Whitney et al., 1967; Whitney and Green, 1969; Whitney, 1970). Centro fixed about 270 kg N $ha^{-1}yr^{-1}$ in Hawaii (Whitney et al., 1967). Even higher N-fixation has been reported for the leguminous shrub *Leucaena leucocephala* (Lam.) de Wit. (Brewbaker et al., 1972).

The acetylene reduction technique (Hardy et al., 1968) has provided useful information regarding N fixation of temperate legumes as affected by cutting, grazing, or fertilization (Moustafa et al., 1969; Sinclair, 1973; Chu and Robertson, 1974; Halliday and Pate, 1976) or by water stress (Engin and Sprent, 1973). However, there is little information on how defoliation or shading affects N fixation by tropical forage legumes. We therefore studied the influence of shading on the performance of six legumes commonly grown in the tropics.

MATERIALS AND METHODS

Six forage legumes were grown in the field on an Oxic Hapulstoll near Paia, Hawaii (20°55'N, 156°22'W and 100 m elevation) during July 1975 to February 1977. Legumes replicated three times were: *Centrosema pubescens* Benth. 'centro'; *Desmodium intortum* (Mill.) Urb. cv. Greenleaf;

[1] Journal Series No. 2499 of the Hawaii Agric. Exp. Stu. This work is part of a dissertation presented by the senior author in partial fulfillment of the requirements for the Ph.D. degree in Agronomy at the Univ. of Hawaii and was supported jointly by the Hawaii Agric. Exp. Stn. and the USAID Contract ta-C-1207 (NifTAL Project, P.O. Box 0, Paia, Hawaii 96779). Received 27 Oct. 1980.

[2] Former research assistant and agronomist, respectively, Dep. of Agronomy and Soil Science, Univ. of Hawaii, College of Agriculture and Human Resources, Honolulu, Hawaii, College of Agriculture and Human Resources, Honolulu, Hawaii 96822. Present address of senior author: Mailing Agricultural College, 8340 Mailing, Denmark.

and *Macroptilium atropurpureum (D.C.)* Urb. cv. Siratro. Legumes not replicated were: *Desmodium canum* (Gmel.) Schintz and Thellung 'kaimi clover'; *Leucaena leucocephala* (Lam.) de Wit. cv. Hawaiian Giant; and *Stylosanthes guianensis* Swartz cv. Schofield.

Plants were grown under four radiation regimes: 100, 70, 45, and 27% of full solar shortwave radiation. Shading treatments were provided by three densities of polypropylene screening stretched over plots 1.9 m above the ground, to allow air circulation and easy passage underneath. The sides facing East and West slanted downward 45 degrees to 1 m above ground, to shade plants from the sun in morning and evening. Each shaded block measured 12.2 x 13.4 m.

In a split-plot experiment radiation regimes were whole plots and legumes sub-plots. For each subplot (2.6 x 3.2 m), 5 m^2 was harvested for yield determinations.

Before planting all plots were fertilized with 150 kg P ha^{-1} as triple superphosphate and 180 kg K ha^{-1} as muriate of potash. Lime was applied at a rate of 3,400 kg ha^{-1} to raise the pH to about 6.3. Additional P (80 kg ha^{-}) was applied 1 year later and additional K (90 kg ha^{-}) was applied 6 and 12 months after establishment.

Water to supplement natural rainfall (≈2,400 mm) was applied by sub-surface drip irrigation with polyethylene tubes (13 mm ID) buried 15 cm deep and spaced 90 cm apart. To compensate for lower water use by shaded plants, emitter spacing was varied so that treatments receiving 100, 80, 45, and 27% full sun received water in proportions of 100, 89, 72, and 50%, respectively.

Seeds were scarified in concentrated sulfuric acid for 5 min, washed, dried, and inoculated with commercial *Rhizobium* cultures. The legumes were seeded in July 1975 and shaded 2 months later. The legumes were cut every 8 weeks during November 1975 to February 1977, with a small sicklebar mower (to 4 to 7 cm stubble height) except for Hawaiian Giant, which was cut by hand to 35 cm stubble height.

[1] Supplied by the Nitragin Co., Milwaukee, Wis. No endorsement is implied.

The parameters measured were: green weight, dry weight, N concentration, mineral concentration, sward height, and acetylene reduction activity. Samples for acetylene reduction were taken 1 week before harvesting in August, October, and December 1976 and February 1977, and 2 and 4 weeks after the 25 Aug. 1976 harvest. Three soil cores per plot (8 cm diam by 15 cm deep) were removed with a soil auger and with as little disturbance as possible were placed in 1,000 ml plastic bottles. Then 100 ml of air was removed and 100 ml of acetylene (10% of the volume) was introduced within 5 min after sampling. After incubation at ambient temperature (-30 C) for 1.5 hours, 0.5 ml was removed and ethylene production determined by gas chromatography. Estimated N fixation was calculated by subtracting the average of N uptake of three grasses *(Brachiaria miliiformis, Digitaria decumbens* and *Panicum maximum)* grown adjacent to the legume plots (Eriksen and Whitney, 1981).

After split-plot analysis of variance, mean differences were based on the Bayes L.S.D. The results from the unreplicated legumes were adjusted by the methods for augmented design described by Federer and Raghavarao (1975). However, it was not considered feasible to compute L.S.D. values for the augmented plots, and we therefore compare the unreplicated treatments in general terms only.

RESULTS AND DISCUSSION

General Observations

Solar radiation in full sun and average daily noon temperatures at 5 cm depth under a grass sward are shown in Fig. 1. Solar radiation averaged only about 400 cal $cm^{-2} day^{-1}$ during the cloudy cool season (November to January) but averaged over 650 cal $cm^{-2} day^{-1}$ during summer (June through September). Soil temperature at full sun ranged from 22.3 C during the cool season to 28 C in summer; temperatures at 27%

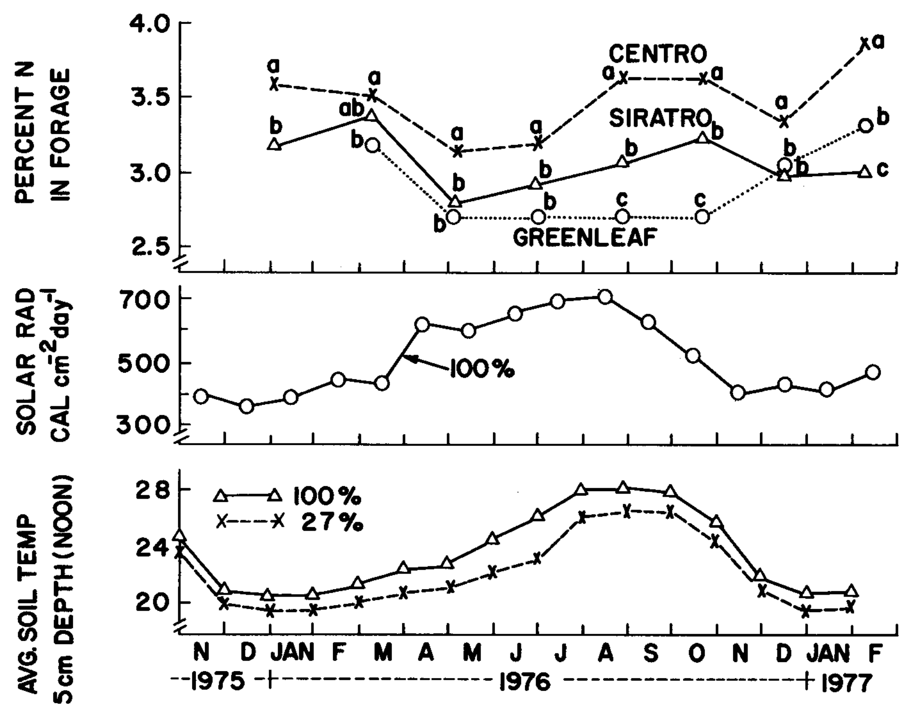

Fig. 1. Percent N of Greenleaf desmodium, centro, and siratro in full sun in relation to solar radiation and soil temperature at 5 cm depth. Also difference in soil temperature between 100 and 27% full sun.

full sun were reduced an average of 1 C (1.5 C in summer).

Initial stands of legumes, except Greenleaf, were good, and growth was relatively uniform among replications. Greenleaf seedings were killed by chinese rose beetles *(Adoretos sinicus);* plots were re-seeded and sprayed regularly with an insecticide. Greenleaf was also sprayed with an insecticide 1 to 2 weeks after each harvest for the 100 and 70% daylight treatments. Siratro growth was severely restricted at 45 and 27% daylight by severe attacks of anthracnose and *Rhizoctonia solani.* During cool moist weather Siratro was sprayed regularly with fungicides to prevent stand losses.

All legumes flowered heavily in full sun, but flowering and seed set were severely reduced with decreased radiation. At 27% full sun, only kaimi clover flowered.

Dry Matter Production

Daily DM production by Greenleaf was higher at all radiation levels and harvest dates than for centro or Siratro (Fig. 2). In full sun DM yields of Siratro and centro were similar, but under reduced radiation centro DM yields surpassed those of Siratro, indicating the better shade tolerance of centro.

There were smaller reductions in DM yields for all legumes during periods of reduced radiation during the cooler months (Fig. 2), when soil temperatures were below 23 C at 5 cm depth (Fig. 1). Also, centro (tropical) seemed to be affected more by cool weather than Greenleaf (subtropical) or Siratro (pan-tropical).

The relative production of DM by the replicated legumes between January 1976 and January 1977 at 100, 70, 45, and 27% full sun were: Greenleaf, 100, 89, 76, and 46%; centro 100, 82, 62, and 44%; and Siratro, 100, 69, 41, and 20%, respectively (Fig. 3).

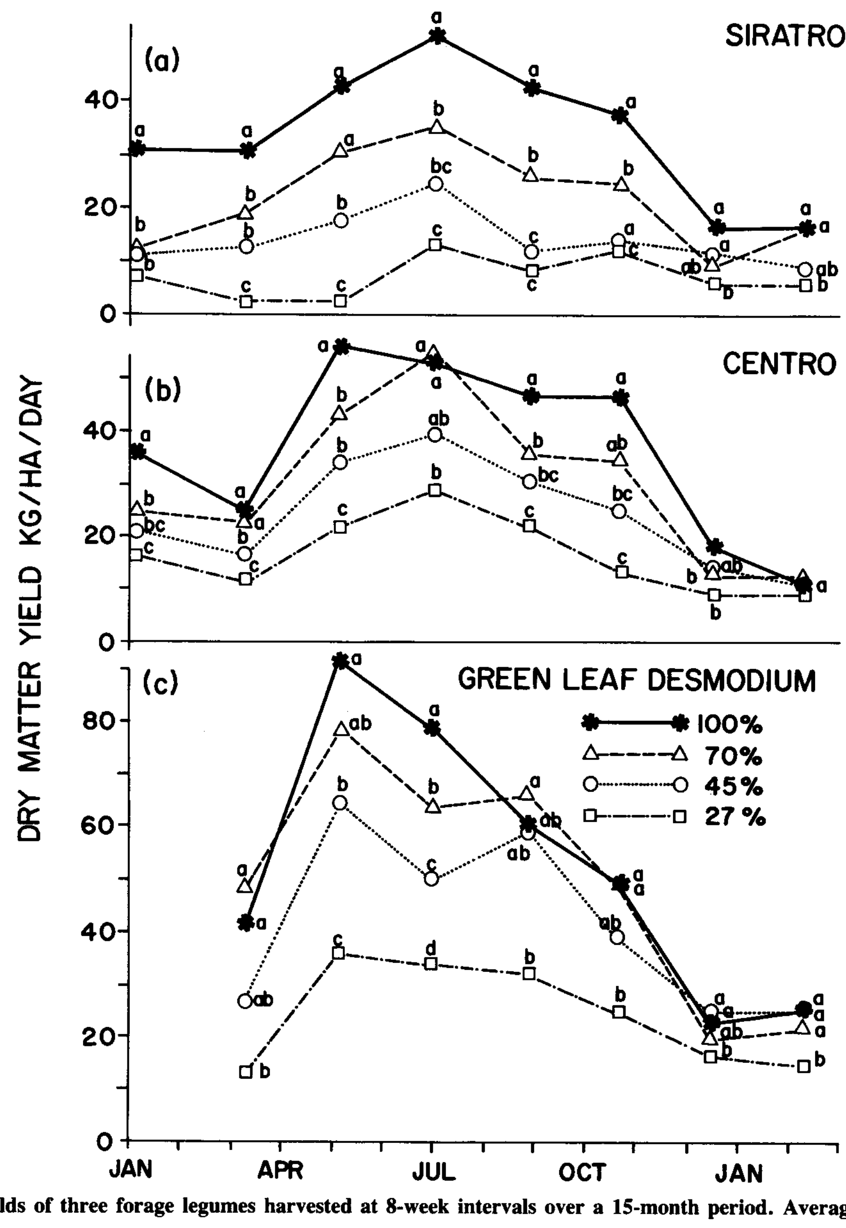

Fig. 2. Dry matter yields of three forage legumes harvested at 8-week intervals over a 15-month period. Average of three replications.

The non-replicated Hawaiian Giant tended to be the highest yielding legume at 100 and 70% full sun, but was similar to Greenleaf at 45 and 17% (Fig. 3). Hawaiian Giant thus seemed to be more sensitive to reduced radiation than was Greenleaf. The DM yield of Schofield stylo was severely reduced as radiation decreased; yield at 27% full sun was only 12% that in full sun. Schofield stands became sparse after prolonged exposure to reduced radiation. The better yield of kaimi clover at 70% full sun than at 100% probably reflects the poor N-fixing potential of this plant. It is thus similar to some grasses which appeared yellow when grown under intense sunlight without N fertilizer, but were green when grown under shade or fertilized with N (Eriksen and Whitney, 1981). We speculate that kaimi clover (and the grasses) did not have sufficient N to replace the chlorophyll which was oxidized by the intense summer sunlight. This is also confirmed by the seasonal differences, i.e., there was less difference among radiation regimes during the cool season (Fig. 2). Increased chlorophyll concentrations under shaded conditions were also noted with alfalfa and birdsfoot trefoil by Cooper and Qualls (1967).

Yields of DM were generally comparable to those reported by other investigators cited in the Introduction. Ranacou (1972) reported that yields of Greenleaf and centro were not as severely depressed by shading (100, 70, 50, and 30% full sun) as were yields of Siratro, or stylo. These results are consistent with our findings. Poor growth of Siratro at low solar radiation has also been reported by Ludlow et al. (1974).

Dry Matter Percentage

Reducing the solar radiation had little influence on DM percentage of any of the six legumes. The average reduction in DM percentage was about 10% at all shade levels (Table 1). This differs from the grasses, where DM percentage declined approximately 1% for every 10% reduction in radiation (Eriksen and Whitney, 1981). Also, in contrast with the grasses, DM percentage varied little with season, and increased only slightly during the cool season. There were, however, differences among legumes (Table 1), with the highest DM percentages occurring in Hawaiian Giant and kaimi clover and the lowest in Siratro (as low as 16.2% DM at 45 and 27% full sun). Low DM concentrations per se are not likely to cause problems, however they are associated with low carbohydrate concentrations in grasses (Hight et al., 1968).

Plant Height

Plant height response was greatest for Greenleaf; plants at 70% full sun were about twice as high as those grown in 100% full sun in both seasons (Table 1). Plants of Hawaiian Giant and Schofield also appeared taller with reduced radiation. Greenleaf, Hawaiian Giant, and Schofield were thus similar to alfalfa *(Medicago sativa L.)* which also grew taller under reduced radiation (Wolf and Blaser, 1972).

The canopy height of the climbing legumes centro and Siratro provided a measure of total volume. Although yields of these legumes declined with decreased radiation, heights of the plant canopies did not differ between radiation regimes. Apparently, plants grown in the shade were more elongated and had wider, thinner leaves, resulting in a lower mass per unit volume than plants grown in full sun.

Concentration and Yield of N and Estimated N Fixation

Concentrations of N in the harvested legumes (DM basis) varied with season (Fig. 1), but were not influenced by radiation regime (Table 1). This agrees with the findings by Bathurst and Mitchell (1958) for tem-

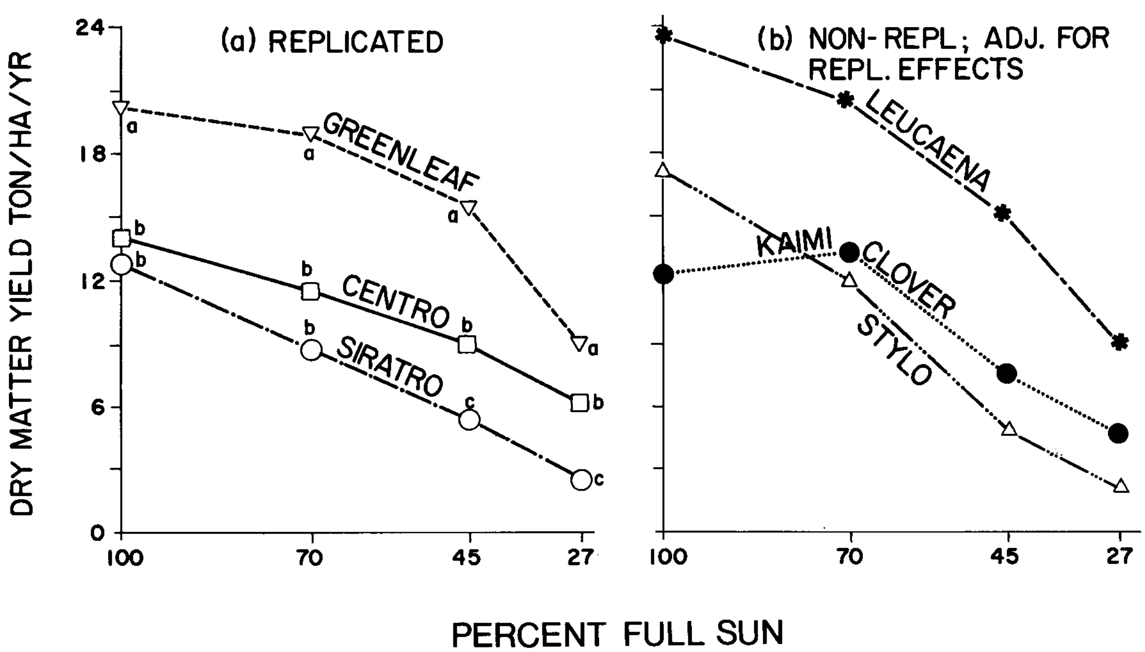

Fig. 3. Influence of four shading regimes on annual dry matter yields of six forage legumes.

perate legumes, but differs from most tropical grasses where the N concentrations increased significantly as radiation decreased (Eriksen and Whitney, 1981). The lowest N concentrations in dry forage occurred early in the warm season and the highest values during the cool season for all legumes (Fig. 1).

Concentrations of N differed between legumes ($P < 0.05$); centro (3. 3% N) > Siratro (3.0% N), > Greenleaf (2.7% N) (Table 1). The low concentration of N in Greenleaf probably reflects extensive loss of leaves prior to harvesting. Concentrations of N in the forage of the non-replicated legumes were about 3.4% in Hawaiian Giant and 2.6% in Schofield and kaimi clover (Table 1.) Thus Hawaiian Giant has an advantage in DM yield plus an even higher N yield.

Total N yields within legumes generally paralleled DM yields, declining with reduced radiation, because the concentrations of N in the forage did not change with radiation regimes (Table 1). However, N yields varied less over seasons than DM yields because the high DM yields measured during the summer season contained a slightly lower percentage of N.

The N yield of Greenleaf (540 kg ha^{-1}yr^{-1} in full sun) is somewhat higher than earlier results from Hawaii (Whitney et al., 1967; Whitney and Green, 1969), probably because the earlier experiments were conducted without irrigation at sites having cooler temperatures and lower solar radiation levels. The high DM and N yields for Hawaiian Giant confirms earlier findings in Hawaii (Brewbaker et al., 1972).

Estimated N fixation by the legumes at 100 and 70% full sun (Table 1) was calculated for each legume by subtracting from the N yield 95 kg N ha^{-1}yr^{-1} (the average forage N yields of the three irrigated grasses grown adjacent to the legume plots at 100 and 70% daylight). Hawaiian Giant apparently had the highest estimated N fixation, exceeding 600 kg ha^{-1}yr^{-1} (data based on only one replication). This is similar to the high N-fixation rates found for temperate legumes in New Zealand (Melville and Sears, 1953), Australia (Henzell and Norris, 1962), and Hawaii (Rotar et al., 1976). Estimated N-fixation values for Greenleaf (> 430 kg ha^{-1}yr^{-1}) and centro (> 315) in the present study were higher than in the earlier studies of Whitney et al. (1967). The grasses grown adjacent to the plots at 45 and 27% full sun took up more soil N with decreasing radiation (up to 250 kg N ha^{-1}yr^{-1} for guineagrass at 27%). However with this exception the grasses took up about 140 kg N at 45 and 27%. On this basis only centro, Greenleaf, and Hawaiian Giant fixed significant quantities of N at 45 and 27% full sun (Table 1). Wong and Wilson (1980) also noted increased uptake of a relative of guineagrass (green panic) under 40% full sun.

Acetylene Reduction Activity

The highest average acetylene reduction rates during August 1966 to February 1977 occurred with Greenleaf and centro; both were higher than the other legumes even under 27% full sun (Table 2). Since these legumes were also the most shade tolerant, the higher acetylene reduction activity probably indicates superior assimilation of carbon under shaded conditions.

Table 1. Effects of shading on plant height, dry matter content, N content, annual N yield, and apparent N fixation (legume N yield less minus-N grass yields) of six forage legumes.

Radiation regime	Centro*	Siratro*	Greenleaf*	Hawaiian Giant†	Schofield Stylo†	Kaimi clover†	Average‡
a) Plant height (cm)							
25 August harvest							
100	28 a	29 a	43 c	125	16	20	100
70	28 a	26 a	73 a	136	31	26	156
45	28 a	27 a	76 a	128	23	23	135
27	28 a	23 a	60 b	136	16	16	112
10 February harvest							
100	17 a	14 a	17 c	41	20	11	100
70	15 a	14 a	34 a	90	18	11	153
45	16 a	15 a	36 b	63	18	11	139
27	17 a	14 a	25 b	65	26	11	134
b) DM content (%)							
100	20.2 a	18.4 a	20.2 a	24.4	20.8	30.3	100
70	18.6 a	17.2 a	18.1 b	24.0	19.2	23.3	90
45	18.8 a	16.1 a	17.9 b	23.2	18.7	24.3	89
27	18.5 a	16.2 a	18.8 ab	22.7	18.9	26.9	91
c) Nitrogen content (%)							
100	3.3 a	2.8 a	2.6 a	3.4	2.8	2.5	100
70	3.5 a	3.0 a	2.8 a	3.5	2.7	2.6	104
45	3.2 a	3.0 a	2.7 a	3.3	3.0	2.6	102
27	3.3 a	3.1 a	2.7 a	3.5	2.7	2.7	103
d) Annual N yield (kg ha^{-1})							
100	461 a	362 a	540 a	751	496	340	100
70	410 a	265 b	528 a	710	321	361	88
45	293 b	160 c	414 b	456	151	186	56
27	205 c	83 d	245 c	285	88	128	35
e) Estimated N fixation (kg ha^{-1})							
100	366	267	455	656	401	245	100
70	315	170	433	615	226	266	85

† Unreplicated; data adjusted for replication effects.
‡ Calculated as a percentage of the values for 100% full sun. Height averages exclude the viny legumes centro and siratro.
* Means within species by radiation level groupings followed by a different letter are different at approximately the 5% level (Bayes' L.S.D.).

Table 2. The influence of shading on the acetylene reduction of tropical forage legumes. Average of six harvests between 16 Aug. 1976 and 9 Feb. 1977.

	C_2H_2 reduction by root nodules in $\mu M\ m^{-2}\ hr^{-1}$						
Radiation regime	Centro	Siratro	Greenleaf	Hawaiian Giant†	Schofield Stylo†	Kaimi clover†	Average‡
100	432	144	468	204	135	198	100
70	450	108	423	105	96	180	86
45	429	60	339	87	39	147	70
27	318	39	222	75	15	75	47
Correlation with							
DM yield	0.80	0.996**	0.99**	0.80	0.99**	0.92	
Radiation level	0.71	0.995**	0.95*	0.93	0.96*	0.92	

*,** Signfiicant at the 5 and 1% level, respectively.
† Unreplicated; data adjusted for replication effects.
‡ Calculated as a percentage of the values at 100% full sun.

Table 3. Effects of shading, season, and legume species on the mineral concentrations in legume top growth. Averages of centro, Siratro, and Greenleaf desmodium.

Treatments effects	P	K	Ca	Mg	S	Cu	Zn
Shade effects							
100%	0.304	2.20	0.97	0.345	0.232	19.4**	36.4
27%	0.313 NS	2.47*	1.04 NS	0.386***	0.225 NS	16.7	34.9
Season effects							
Warm	0.292	2.33	1.00	0.352	0.224	19.**	34.3
Cool	0.326***	2.35 NS	1.01 NS	0.379*	0.232 NS	16.8	37.0**
Species effects	***	**	NS	***	***	***	***

*,**,*** Different at the 5, 1, and 0.01%, respectively by Bayes L.S.D. test.

Also, the rooted stolons of both Greenleaf and centro had numerous nodules at the soil surface, while the other legumes had none. The lower acetylene reduction by Hawaiian Giant leucaena may be an artifact of the sampling procedure, since its deeper roots may have had nodules which were not recovered. Generally, the acetylene reduction data within species were highly correlated with DM yields (r = 0.80 to 0.996) and with radiation regimes (r = 0.92 to 0.995, except for centro which was 0.71) (Table 2).

Acetylene reduction rates (for the two harvests sampled at 2 and 4 weeks after harvesting) were lowest at 2 weeks for all six legumes and at all levels of radiation (data not presented). There was a pronounced radiation effect; 50 to 85% of the pre-harvest maximum under 100 and 70% full sun vs. 0 to 65% of maximum under 45 and 27% full sun. Defoliation resulted in the most severe reduction in acetylene reduction activity in centro and Siratro and the least reduction in Greenleaf and kaimi clover.

Decreased acetylene reduction activity following defoliation or shading or both was reported for white clover *(Trifolium repens L.)* by Moustafa et al. (1969). The deleterious effects of defoliation and shading on nodulation have also been reported for temperate pasture legumes (Butler et al., 1959) and for tropical pasture legumes (Whiteman and Lulham, 1970). Chu and Robertson (1974) attributed the decreased acetylene reduction activity to decreases in nodule mass rather than to decreased specific activity. Halliday and Pate (1976) reported that defoliation caused acetylene reduction to drop to about 10% of pre-defoliation levels within hours. Acetylene reduction capacity then returned to about 30% of that of the uncut control plants within 1 week after defoliation. In our experiments there was probably partial recovery of acetylene reduction activity because our earliest sampling period was 2 weeks after cutting. However, the data indicate a longer recovery period for plants grown under shade. There were also differences among species with respect to their capacity to re-establish high rates of acetylene reduction activity after cutting, with the Desmodiums having the fastest recovery.

Mineral Composition

Mineral compositions in the forage legumes at 100, 70, and 45% full sun did not differ significantly at any season except that K concentration increased with decreasing radiation during the warm season. The plants grown in dense shade (27% full sun) had slightly higher concentrations of K and Mg, lower concentrations of Cu, essentially no difference in concentrations of P, Ca, S, and Zn (Table 3). Concentrations of P, Mg, and Zn were higher during the cool season than during the warm season. Mineral concentrations of the three replicated species varied significantly among species for all minerals, except for Ca (Table 3).

We therefore conclude that although mineral concentrations varied among the legumes studied, shading did not cause any deterioration in nutritive value, and nutrient deficiencies probably did not occur since mineral concentrations were all above generally accepted critical levels for clovers (Chapman, 1966).

LITERATURE CITED

Bathurst, N. O., and K. J. Mitchell. 1958. The effect of light and temperature on the chemical composition of pasture plants. N. Z. J. Agric. Res. 1:540-552.

Brewbaker, J. L., D. L. Plucknett, and V. Gonzalez. 1972. Varietal variation and yield trials of *Leucaena leucocephala* (Koa Haole) in Hawaii. Hawaii Agric. Exp. Stn. Bull. No. 124.

Butler, G. W., R. M. Greenwood, and K. Soper. 1959. Effects of shading and defoliation on the turnover of root and nodul8 tissue of plants of *Trifolium repens, Trifolium pratense,* and *Lotus uliginosus*. N. Z. J. Agric. Res. 2:415-426.

Chapman, H. O. 1966. Diagnostic criteria for plants and soils. Univ. of Calif. Press.

Chu, A. C. P., and A. G. Robertson. 1974. The effects of shading and defoliation on nodulation and nitrogen fixation by white clover. Plant Soil 41:509-519.

Coaldrake, J. E. 1964. Sub-tropical environment of eastern Australia. a) Climate Bull. Commonw. Bur. Pasture Field Crops 47:17-26.

Cooper, C. W., and M. Qualls. 1967. Morphology and chlorophyll content of shade and sun leaves of two legumes. Crop Sci. 7:672-673.

Date, R. A. 1973. Nitrogen, a major limitation in the productivity of natural communities, crops and pastures in the Pacific Area. Soil Biol. Biochem. 5:5-8.

Engin, M., and J. I. Sprent. 1973. Effects of water stress on growth and nitrogen-fixing activity of *Trifolium repens*. New Phytol. 72:117-126.

Eriksen, F. I., and A. S. Whitney. 1981. The effects of light intensity on the growth of some tropical forage species. I. Interaction of light intensity and nitrogen fertilization on six forage grasses. Agron. J. 73:427-433.

Federer, W. T., and D. Raghavarao. 1975. On augmented designs. Biometrics 31:29-35.

Halliday, J., and J. S. Pate. 1976. The acetylene-reduction assay as a means of studying nitrogen fixation in white clover under sward and laboratory conditions. J. Brit. Grassl. Soc. 31:29-35. Hardy, R. W. F., R. D. Holsten, E. K. Jackson and R. C. Burns. 1968. The acetylene-ethylene assay for N_Z fixation: laboratory and field evaluation. Plant Physiol. 43:1185-1207.

Henzell, E. F., and D. O. Norris. 1962. Processes by which nitrogen is added to the soil/plant system. *In* A review of nitrogen in the tropics with particular reference to pastures. Bull. Commw. Bur. Past. Field. Crops 46:1-18.

Hight, G. K., D. P. Sinclair, and R. J. Lancaster. 1968. Some effects of shading and of nitrogen fertilizer on the chemical composition of freeze-dried and oven-dried herbage and on the nutritive value of oven-dried herbage fed to sheep. N. Z. J. Agric. Res. 22:286-302.

Hugh, E. I. 1972. Regional seminar on pastures and cattle under coconuts, Western Samoa, 30 Aug.-12 Sept. South Pac. Comm., Noumea, New Caledonia. 156 p.

Javier, E. Q 1974. Improved varieties for pastures under coconuts. Extn. Bull. No. 37. ASPAC, FFTC, 12 p.

Ludlow, M. M., G. L. Wilson, and M. R. Heslehurst. 1974. Studies on the productivity of tropical pasture plants. Effect of shading on growth, photosynthesis and respiration in two grasses and two legumes. Austr. J. Agric. Res. 25:425-433.

Melville, J., and P. D. Sears. 1953. Pasture growth and soil fertility. II. The influence of red and white clovers, superphosphate, lime and dung and urine on the chemical composition of pastures. N. Z. J. Sci. Tech. 35A Suppl. 1:30-41.

Moustafa, E., R. Ball, and T. R. O. Field. 1969. The use of acetylene reduction to study the effect of nitrogen fertilizer and defoliation on nitrogen fixation by field grown white clover. N. Z. J. Agric. Res. 12:691-696.

Ng, T. T., and T. H. Wong. 1976. Comparative productivity of two tropical grasses as influenced by fertilizer nitrogen and pasture legumes. Tropic. Grassl. 10:179-185.

Olsen, F. J., and P. G. Moe. 1971. The effect of phosphate and lime on the establishment, productivity, nodulation and persistence of *Desmodium intortum, Medicago sativa* and *Stylosanthes gracilis*. E. Afr. Agric. For. J. 37:29-37.

Plucknett, D. L., and R. L. Fox. 1965. Effects of phosphorus fertilization on yields and composition of pangola grass and *Desmodium intortum*. Proc. 9th Int. Grassl. Cong. 1525-1529.

Ranacou, E. 1972. Pasture species under coconuts. p. 95-102. *In* E. Hugh (ed.) Regional Seminar on pastures and cattle under coconuts. 30 Aug.-12 Sept. 1972. South Pac. Comm. Noumea, New Caledonia.

Rotar, P. P., Y. N. Tamimi, O. R. Younge, and T. Izuno. 1976. Forage legume production trials at the Volcano Research Station, Island of Hawaii. Hawaii Agric. Exp. Stn. Bull. No. 206.

Santhirasegaram, K., J. E. Coaldrake, and M. H. M. Salih. 1966. Yield of a mixed sub-tropical pasture in relation to frequency and height of cutting and leaf-area index. p. 125-129. *In* Proc. 10th Int. Grassl. Cong.

Sinclair, A. G. 1973. Non-destructive acetylene-reduction assay of nitrogen fixation applied to white clover plants growing in soil. N. Z. J. Agric. Res. 16:263-270.

Whiteman, P. C., and A. Lulham. 1970. Seasonal changes in growth and nodulation of perennial tropical pasture legumes in the field. I. The influence of planting date and grazing and cutting on *Desmodium incinatum* and *Phaseolus atropurpureus*. Austr. J. Agric. Res. 21:195-206.

Whitney, A. S. 1970. Effects of harvesting interval, height of cut, and nitrogen fertilization on the performance of *Desmodium intortum* mixtures in Hawaii. p. 631-636. Proc. 11th Int. Grassl. Cong.

and R. E. Green. 1969. Legume contributions to yields and compositions of *Desmodium* spp.-pangola grass mixtures. Agron. J. 61:741-746.

Y. Kanehiro, and G. D. Sherman. 1967. Nitrogen relationships of three tropical forage legumes in pure stands and in grass mixtures. Agron. J. 59:47-50.

Wolf, D. D., and R. E. Blaser. 1972. Growth rate and physiology of alfalfa as influenced by canopy and light. Crop Sci. 12:23-26. Wong, C. C., and J. R. Wilson. 1980. Effects of shading on the growth and nitrogen content of green panic and Siratro in pure and mixed swards defoliated at two frequencies. Aust. J. Agric. Res. 31:269-285.

Younge, O. R., D. L. Plucknett, and P. P. Rotar. 1964. Culture and yield performance of *Desmodium int*ortum and *D. canum* in Hawaii. Hawaii Agric. Exp. Stn. Bull. No. 59.