Influence of Intra-Row Spacing and Cutting Regimes on the Growth and Yield of Leucaena[1]

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ABSTRACT

Leucaena *(Leucaena leucocephala* (Lam.) de Wit) has proven to be a very productive tropical legume, but the factors which control production under intensive management have not been well defined. Thus three harvest frequencies (based on attained plant height), three population densities, and two plant types of leucaena were evaluated at North Kohala, Hawaii (120-m elevation, Typic Ustropept). Plants of K341 (a shrubby "Hawaiian" type) and K8 (an arboreal "Salvador" type) were grown at spacings of 15 X 50, 30 X 50, and 45 X 50 cm, and harvested when plants attained average heights of 55, 105, or 155 cm. Stem elongation rates and yields were highest during periods of high solar radiation and high night temperature. Selection K341 tended to flower at an early stage, especially at the lower planting densities, with consequent reduction in vegetative growth. Selection K8 increased in height more rapidly than K341 and thereby intercepted more sunlight until about 14 weeks when light interception values were similar at 96%.

Yields increased with less frequent cutting. Total dry matter yields when cut at attained heights of 55, 105, and 155 cm (about 2 1/2, 3, and 4 months growth duration) were 11.9, 16.9, and 20.8 metric tons/ha, respectively. However, the percentage forage fraction was higher under more frequent cutting; averaging 79, 68, and 59% for the same three treatments. Percentage forage fraction also tended to be slightly higher at the highest plant density, since leucaena was unable to compensate for wide spacing by producing more shoots. Plant type, spacing, and cutting treatments did not affect the levels of N or mimosine in the forage fraction (4.3 and 6.7% respectively) or in the stem fraction (1.5 and 0.9%, respectively. K341 yielded nearly 600 kg N ha^{-}lyear^{-1}. in the forage fraction while K8 yielded about 500 kg N ha^{-1}year^{-1}.

Dense planting (15 X 50 cm) and cutting when the plants were approximately 1 m in height were desirable management practices considering forage yield, percentage forage fraction, forage quality, flowering behavior, and average cutting frequency (3 months).

***Additional index words: Ipil-ipil,* Koa haole, Forage yield, N yield, Mimosine.**

LEUCAENA *(Leucaena leucocephala* (Lam.) de Wit, is a tropical legume which has spread over a wide range of topographical and climatic conditions in the tropics. In some areas leucaena is cut on a regular basis for fuel. If the leafy portions are returned to the soil, considerable quantities of N and other minerals are added to the system. It should be similarly possible to exploit the N fixed by leucaena for food crop systems.

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[3]R. C. Mendoza, T. P. Altamarino, and E. Q. Janier. *1975* Herbage, crude protein, and digestible dry matter of ipil-ipi *(Leucaena latisiliqua (L.)* Gillis cv. Peru) in hedge rows. Pape presented to Philippine Soc. Anim. Sci. Annu. Scientific Con vention, Manila.

Leucaena has also been shown to improve the physical condition and fertility of soil when the leaves and twigs are plowed into the soil (8, 9).

Leucaena is useful as a pasture plant because of the high protein browse it provides (6). However, its nutritional value as animal feed is sometimes offset by the presence of mimosine, R[-N-hydroxypyridone-4]a-aminopropionic acid, an amino acid which causes loss of hair on nonruminants and, in large quantities, affects thyroid function in ruminants. Mimosine content in the plant varies throughout the year, and the growing young leaves contain the highest level (4). When the intake of leucaena is carefully controlled, it can be a very useful feed even for non-ruminants.

Several previous workers have studied certain aspects of leucaena management in relation to yield, nutritional value, and persistence. Takahashi and Ripperton (11) showed that neither persistence nor overall yield of Hawaiian (shrubby) type of leucaena was affected by varying the time to first harvest. A short (4 month) period of establishment was recommended because of the high yields obtained, the ease of harvesting of the crop, and the better quality of forage obtainable from younger growth.

Several preliminary yield trials of the Salvador (arboreal) type in various countries have been reported. In Samford, Queensland, the Salvador strains yielded five times more forage than the Hawaiian strain with no loss in proportion of leafy fraction or protein content (5). Yield of dry matter and protein from Salvador-type leucaena exceeded that of good irrigated Lucerne in southern Queensland and was comparable with the yield from high quality clover (*Trifolium* sp.) ryegrass (*Lolium multiflorum* L.) pasture in New Zealand.

Yield trials in the Virgin Islands showed that the dry matter yields of the Salvador-type selections were 50% higher than the Hawaiian-type selections (10). In recent advanced yield trials in Hawaii, the Salvador types yielded two and one half times as much forage as the Hawaiian types (1).

In the Philippines, dry matter yields of 'Peru' leucaena ranged from 9.5 to 24.1 metric tons ha^{-1}$_{year}$$^{-1}$ when planted in rows 3 m apart under cutting heights of 15 cm to 3 m and cutting frequencies of 8 to 16 weeks. Taller hedgerows produced higher dry matter yields. Dry matter yield was not influenced by the frequency of cutting[3].

Although leucaena now has wide geographical distribution and is widely accepted as a potentially productive source of high quality forage, research on the agronomic management of leucaena is still quite limit-

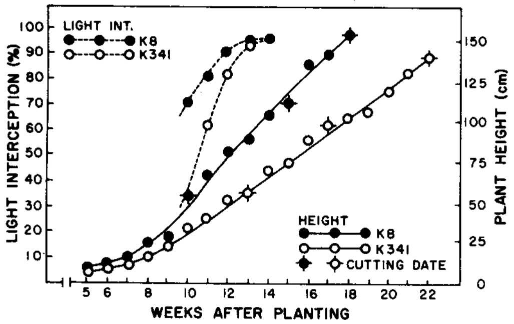

Fig. 1. Light interception and plant heights of two types of leucaena following initial establishment.

ed. In order to more fully exploit this potential, a better understanding is needed of the growth characteristics of different plant types and of the interactions between management and plant performance. Therefore, this experiment was conducted to compare the growth behavior and yield potential of two distinct varietal types of leucaena and to determine the optimum plant spacing and harvesting interval (as defined by attained height) for maximum forage production.

MATERIALS AND. METHODS

Two cultivars of leucaena, K341 and K8 (PI 263695) were planted at North Kohala, Hawaii (130-m elevation, Typic Ustropept) on 27 Mar. 1974. K341 is a shrubby "Hawaiian" type naturalized in Hawi, Hawaii, and designated as "Kohala". K8 is an arboreal "Salvador" type from Mexico commonly known as "Hawaiian Giant" (1, 2, 3). The seeds were inoculated with a commercial *Rhizobium* inoculant before planting.

Plots were arranged in a factorial split plot design with leucaena cultivars as main plots, cutting regimes as sub-plots, and intra-row plant spacing as sub-sub-plots. Plots were replicated four times. Rows were spaced 50 cm apart and intra-row plant spacings were 15, 30, and 45 cm corresponding to populations of about 133,000, 66,000, and 45,000 hills/ha, respectively, with two to three plants per hill. Cutting regimes involved harvesting when plants reached average heights of 55, 105, and 155 cm. The plots were cut over a period of 15 to 16.5 months (depending on cutting regime) and the results were converted to a 12-month basis.

The plants from each plot were separated into forage and stem fractions at each harvest. The forage fraction consisted of the leaves plus the green, soft portions of the stems. Measurements were also taken during one or more growth periods of weekly increase in plant height, stem diameter at harvest (>5 mm), number of stems (>5 mm) at harvest, number of stems with distinct flower buds at harvest, percent light interception, and N and mimosine contents. Plant height was measured from ground level to the uppermost tip of the growing bud of four randomly selected plants. Stem diameter was measured near the middle of the brown portion of the stem (since stem length varied with cutting treatment). Light interception was measured at about 1000 hours and was calculated on the basis of the blue radiation levels measured above the crop canopy and at the ground surface. Total N in the plant samples was determined by the Kjeldahl method. Mimosine was determined colorimetrically (7).

RESULTS AND DISCUSSION

Development of leucaena plants could be conveniently divided into three phases on the basis of increase in height (Fig. 1): phase "A", the seedling establishment phase of about 5 weeks duration; phase "B", the lag phase lasting 3 to 4 weeks; and phase "C", the active growth phase which also included the flowering period of the Hawaiian selection K341. Phases B and C also described regrowth subsequent to cutting.

Both cultivars established rather slowly and had similar growth characteristics during phase A. During phase B, K-8 increased in height more rapidly than K341. This was associated with differences in growth habit. K8 plants tended to produce a small number of apically dominant stems whereas K341 plants produced many shoots and lateral branches resulting in a bushy growth habit. During phase C, K341 plants began to flower, further restricting their rate of growth compared to the K8, which did not flower under any of the harvesting regimes.

The lag phase (B) of regrowth after cutting was minimal for plants which were cut at attained heights of 55 or 105 cm. However, if the plants were not cut until they attained a height of 155 cm, the lag phase was longer and the slower stem elongation rate of cultivar K341 was again significant. This was probably due to the "sink" effects of flowers and pods on the K341 plants which probably restricted carbohydrate accumulation in the roots and lower stems prior to harvest. This would then depress the rate of regrowth because of limited substrate for N fixation, active nutrient uptake, and new tissue formation. Unlike alfalfa *(Medicago sativa L.),* leucaena does not produce vegetative buds at the base of the plant before cutting, and therefore is slower to recover after each cutting.

Over a 1-year period, K341 plants attained a height of 55 cm at an average of 76 days, 105 cm at 100 days, and 155 cm at 126 days. K8 plants reached these same heights approximately 10 days earlier; 65, 91, and 115 days, respectively.

Light interception values (blue light, moderate sun angle) also showed differences between plant types. Ten weeks after planting, K8 intercepted 35% more light than K341 (Fig. 1). The difference in the amount of light intercepted by the two cultivars decreased with time so that light interception at 14 weeks was nearly identical; 96.6% for K341 and 96.3% for K8. There were no significant differences in light interception values (measured at ground level) among plant spacing treatments. Higher light interception by K8 during the vegetative growth stage largely reflected its rapid upright growth. K8 thus should have a modest advantage in utilizing sunlight more efficiently, and in competing more effectively with weeds during regrowth.

The number of stems per ha was not significantly affected by cultivar or height at cutting (Table 1). However the number of stems per ha was significantly reduced at the wider plant spacings. Unlike most tillering plants, leucaena was apparently not able to compensate for wide spacing by producing more stems. Thus the selection of the most favorable spacing or planting density is an important consideration in optimizing dry matter yield and percent forage fraction.

Stem diameter varied with both cutting interval and plant spacing (Table 1). Stems were larger under infrequent cutting (higher attained height at harvest) and at lower plant densities. There was no difference in stem diameter between cultivars (average stem diameter = 8.2 mm).

Flowering stems were noted only on K341 (Table

Table 1. Analysis of treatment effects on stem characteristics and production of dry matter and N of leucaena growth for forage.

Treatment variables	Stem characteristics: Total no.	Average diameter	Percent flowering†	Annual DM yield: Forage fraction	Stem fraction	Forage fraction	Annual N yield: Forage fraction	Stem fraction
	1,000/ha	mm	%	tons/ha	tons/ha	%	kg/ha	kg/ha
Cultivar								
K341	268 a*	8.4 a	25	12.0 a	5.8 a	70 a	513 a	84 a
K8	237 a	8.0 a	–	9.9 b	5.3 b	67 b	429 b	72 a
Height at cutting								
55 cm	266 a	6.4 c	21 b	9.4 c	2.6 c	79 a	410 c	40 c
105 cm	245 a	8.4 b	35 a	11.5 b	5.4 b	68 b	482 b	79 b
155 cm	248 a	9.8 a	20 b	12.0 a	8.8 a	59 c	521 a	115 a
Intra-row spacing								
15 cm	344 a	7.3 c	9 c	11.8 a	6.2 a	67 c	507 a	88 a
30 cm	237 b	8.2 b	21 b	11.0 b	5.6 b	69 b	467 b	79 b
45 cm	177 c	9.1 a	43 a	10.1 c	4.9 c	70 a	439 c	67 c

* Means in the same column of pair or triplet followed by the same letter are not significantly different at approximately the 5% level (Bayes LSD).
† Excluding K-8 which did not flower in any of the treatments.

1), with plant spacing influencing the number of flowering stems more than harvesting interval. The most flowering occurred at the wider spacings.

Dry Matter Yields. The average overall dry matter yields were 17.8 metric tons $ha^{-1}year^{-1}$ for K341 and 15.2 for K8 (Tables 1 and 2). These yields consisted of 12.0 tons of the forage fraction and 5.8 tons of the stem fraction for K341, and 9.9 tons of forage fraction and 5.3 tons of stem fraction for K8. These results are different from the results of the earlier experiments in which yields of the Salvador types of leucaena were much higher than yields of the Hawaiian types (1, 5).

Dry matter yields under frequent cutting were lower than those under less frequent cutting. However, the proportion of stems was greater under infrequent cutting. The data suggest that planting at 15-cm spacing and cutting when the plants reached about 1 m height resulted in near optimum yields. At this stage, stem content was not excessive, and harvesting interval was moderately long (13 to 15 weeks). However, the cutting interval could be further shortened with only a moderate penalty in forage fraction yields if a low proportion of stem in the forage was deemed important.

Most of the additional yield realized under infrequent cutting was stem material. As height at time of cutting increased from 55 to 155 cm, the annual yield of forage fraction increased 28%; while stem fraction yield increased 240%. This was partly a result in shedding of lower leaves due to excessive shading among the taller plants. This is confirmed by the increasing percentage of stem fraction in leucaena cut less frequently; 21, 32, and 41% for harvests at attained heights of 55, 105, and 155 cm, respectively (Table 1). As plant spacing increased, yields of both forage and stem fractions decreased.

The low dry matter yields associated with frequent cutting seemed to be related to the increased number of lag recovery phases during which the rate of dry matter production was very low. Whiteman and Lulham (12) state that a severe check in growth such as close cutting results in mobilization of sugars and amino acids from the roots to support the development of new leaves. During this time, root growth and N fixation are severely suppressed, further limiting the production potential of frequently harvested plants.

Table 2. Dry matter yields of forage and stem by two leucaena cultivars as affected by harvesting regime and plant spacing.

Average height at cutting	Intra-row spacing	Annual DM yield: Forage fraction	Stem fraction	Total yield	Forage/total yield
cm	cm	tons/ha	tons/ha	tons/ha	%
Cultivar K341 (Kohala)					
55	15	12.2	3.1	15.3	80
	30	10.8	2.9	13.7	80
	45	9.5	2.2	11.7	82
	Mean	10.8	2.7	13.5	81
105	15	12.9	6.7	19.6	66
	30	12.3	5.5	17.8	69
	45	12.0	5.1	17.1	70
	Mean	12.4	5.8	18.2	68
155	15	13.0	9.2	22.2	59
	30	14.0	10.1	24.1	58
	45	11.5	7.3	18.8	62
	Mean	12.8	8.9	21.7	60
Cultivar mean		12.0	5.8	17.8	70
Cultivar K8 (Hawaiian Giant)					
55	15	9.2	2.9	12.1	76
	30	7.7	2.2	9.9	79
	45	6.8	2.0	8.8	77
	Mean	7.9	2.4	10.3	77
105	15	11.5	5.6	17.1	67
	30	10.2	4.8	15.0	68
	45	10.1	4.5	14.6	69
	Mean	10.6	5.0	15.6	68
155	15	11.7	9.6	21.3	55
	30	11.3	8.1	19.4	59
	45	10.8	8.1	18.9	58
	Mean	11.3	8.6	19.9	57
Cultivar mean		9.9	5.3	15.2	67

† All treatments were harvested over a 455- to 502-day period (4 to 7 total cuts).

Forage fraction yields from all treatments were lower than expected from intensively managed, irrigated leucaena. Yields were about 40% of those previously reported for K8 growing at lowland sites on Maui, Oahu, and Kauai (1), assuming that the reported fresh weight yields contained 25% dry matter. However the yield obtained in this experiment was comparable to that obtained in the Philippines under comparable height and frequency of cutting'. Yields were lower than alfalfa growing at the same site in Kohala. The

Table 3. Nitrogen content and yield of two leucaena cultivars as affected by harvesting regime and plant spacing.

Average height at cutting	Intra-row spacing	Percent N Forage fraction	Percent N Stem fraction	Annual N yield Forage fraction	Annual N yield Stem fraction
cm	cm	%	%	kg/ha	kg/ha
Cultivar K341 (Kohala)					
55	15	4.52	1.63	547	49
	30	4.46	1.63	485	46
	45	4.40	1.59	417	34
	Mean	4.46	1.62	483	43
105	15	4.13	1.54	532	102
	30	3.97	1.60	488	89
	45	4.17	1.50	498	76
	Mean	4.09	1.55	506	89
155	15	4.37	1.45	563	131
	30	4.20	1.37	581	134
	45	4.19	1.36	509	96
	Mean	4.25	1.39	551	120
	Cultivar mean	4.27	1.52	513	84
Cultivar K8 (Hawaiian Giant)					
55	15	4.26	1.60	388	46
	30	4.31	1.61	329	36
	45	4.34	1.63	392	33
	Mean	4.31	1.61	336	38
105	15	4.35	1.45	507	76
	30	4.26	1.42	439	66
	45	4.21	1.36	430	62
	Mean	4.27	1.41	459	68
155	15	4.30	1.27	505	121
	30	4.26	1.28	481	105
	45	4.52	1.25	488	102
	Mean	4.36	1.26	491	110
	Cultivar mean	4.31	1.43	429	72

leucaena may not have achieved its maximum yield potential because the low cutting height chosen (simulating a convenient height for machine operations) left no basal leaves and left inadequate reserves of carbohydrate and protein in the stubble. This is confirmed by recent unpublished results (A. B. Guevarra) which showed that cutting back to 30-cm stubble resulted in much more rapid regrowth than cutting to 5-cm stubble. It is suggested that future studies employ a higher cutting height. This should assure more rapid recovery from cutting, permit lower stand densities (since regrowth could arise from more sites), and better control of weed growth during the recovery period.

Percentage N, N Yield, and Mimosine Content. Overall N percentages were not influenced by cultivar, plant spacing, or cutting interval except that stems declined in N content as harvesting interval increased (Tables 1 and 3). The high constant percentage of N in the forage fraction (over 4.25%) over a wide range of harvesting periods could be very advantageous since it would allow flexibility in harvesting without sacrificing the nutrient value of the forage.

On the average, K341 produced nearly 600 kg N/ha/ year while K8 produced about 500 kg N,/ha/year (Tables 1 and 3). The forage fraction contained about 85% of the total N yields in both cultivars. In general, as in the case of dry matter yields, N yield per year increased with height at cutting and decreased with increasing width of intra-row spacing. The differences

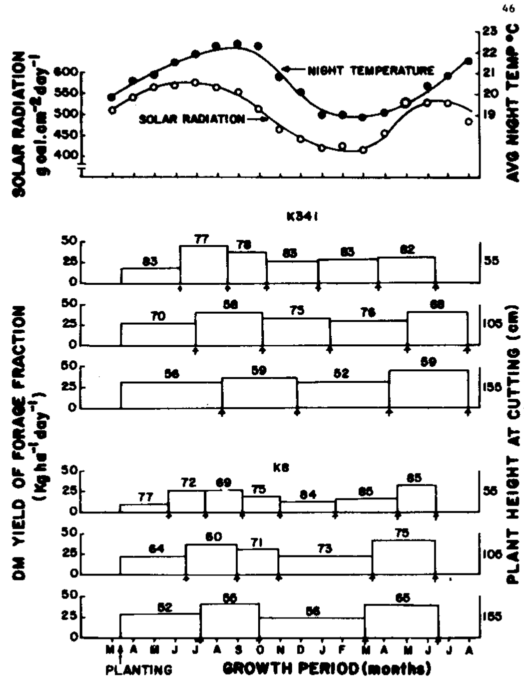

Fig. 2. Relationship of dry matter yields of leucaena forage fraction with average solar radiation and night temperature. Values on the bars are percent forage fraction (average of three intra-row spacings) K341: Upper three graphs, K8: Lower three graphs; ▲ indicates time of cutting.

noted in N yields among treatments were primarily due to differences in dry matter yields.

The average mimosine content was about 6.6% in the forage fraction and 0.9%, in the stem fraction with no significant differences between cultivars, spacings, or cutting regimes. The average crude protein (percent N X 6.25) in the forage and stem fractions consisted of about 24 and 10% mimosine, respectively.

Seasonal Effects of Leucaena Growth. Forage fraction yields were higher during the July to October period (summer) than during November to June (coolseason) (Fig. 2). Solar radiation levels and night temperatures averaged 550 ly/day and 22.2 C respectively during summer and 461 and 19.6 C, respectively, during the cool season. Plants from all treatments responded similarly, but K341 cut at frequent intervals (attained height of 55 cm) typifies the response with an average yield of 40 kg $ha^{-1}day^{-1}$ during summer and 27 kg $ha^{-1}day^{-1}$ during the cool season.

Regrowth periods were longer during the months when solar radiation and night temperature were low, especially under infrequent cutting. For example, the regrowth of K8 required only 85 days to reach 155 cm height during August to October but needed 153 days during October to March.

Forage fraction yields of both cultivars were highly correlated with solar radiation (r>0.90) and to a lesser extent with night temperature: r = 0.68 (K8) and r= 0.81 (K341).

Solar radiation levels and night temperatures did not significantly influence the percentage of forage fraction (Fig. 2) or the percentage of N in the forage fraction.

CONCLUSION

The experiment reported indicates that leucaena has the potential for producing moderately high yields of very high protein forage under intensive management. Good forage fraction yields can be obtained by cutting only every 3 months, thus reducing both the cost of harvesting and the compaction of soil during harvesting. No pest or disease damage was noted, but it was necessary to control weeds with contact herbicide during early regrowth. Although not tested in the present experiment, increasing the height of cutting from 3 to 5 to 25 to 35 cm might be expected to both increase yields and reduce weed problems during regrowth.

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