Leucaena for Forage Production in the Ryukyu Islands

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Introduction

Leucaena leucocephala (Lam.) de Wit was introduced to the Ryukyu Islands in the early 1910's. Initially it was used as fire-wood or organic manure to senescent sugarcane fields. Subsequently it was naturalized in the coastal areas of the Islands, but was not used for any agricultural purpose[6].

Recently, leucaena attracts our attention as low-cost and high quality fodder plants. It might be superior to other feeds available, since leucaena's long research history has already proven the higher forage potential in many sub-tropical countries[1-4]. Although its general usefulness and cultural methods are well-known, there is little information on how to manage it for maximum forage production under the given climatic and soil conditions of the Islands. The papers reported in the Islands on adaptation, productivity, forage quality, and other aspects of leucaena are reviewed in this paper with the purpose of offering a guide to a cultural system for exploiting full forage potential of this plant in the Ryukyu Islands.

Adaptation

The Ryukyu Islands are made up of 64 islands, lying at 24° to 27° north latitude with varying climates and soils[2]. The environmental factors which seem to limit the growth of leucaena are temperature, soil pH and soil salinity[8]. Temperature fluctuates between 18.0 and 29.1°C in the southern edge and 14.0 and 28.5°C in the northern edge of the Islands. Soil pH ranges from 4.0 to 5.5 in Hapludults and 6.0–7.5 in Rhodualfs, both being predominant soils. The highest soil salinity level is greater than 20 mg/g soil on the windward coastal pasture[7,8].

For stable forage production under such an environment, areas suitable for leucaena cultivation in the Islands should be determined for the first step, by examining the growth response of leucaena to temperature, soil pH and soil salinity levels prevailing in the Islands.

1) *Optimal temperature*

Optimal temperature for growth of leucaena seems to be higher than that for other tropical legumes, but it has not been underpinned by experiments.

A phytotron experiment[16] showed that leucaena belongs to the warm tropical legumes with optimal growth temperature of 25.0 to 33.0°C, but yet leucaena showed better growth at above 33.0°C than other species of the group[16]. This result indicates that leucaena will be better adapted to the southern parts of the Islands, and supports the author's observation that leucaena leaves fall with winter wind in the north.

2) *Optimal soil pH*

Ten species of tropical legumes including leucaena (Peruvian) were grown on Hapludults with different pH, ranging from 4.5 to

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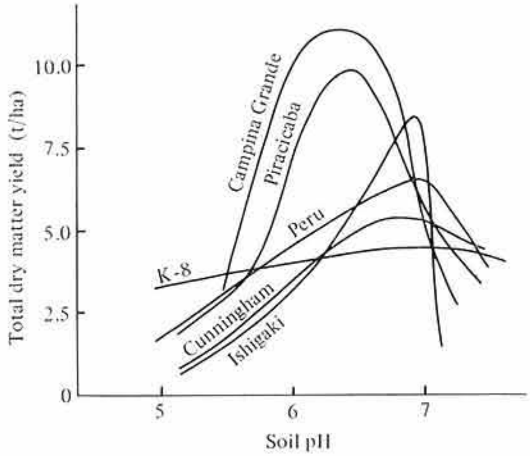

Fig. 1. Response of dry matter production of six lines of leucaena to soil pH

7.0 in the pot experiment[11]. The soil pH was adjusted by adding calcium carbonate to the soil. The result showed that leucaena was an only plant that required soil pH above 6.7 for the normal growth, although some differences among lines were observed in a field experiment where soil pH was adjusted similarly[14].

As given in Fig. 1, the soil pH to maximize the total dry matter production slightly differed among the leucaena lines tested. It was around 6.5 for Piracicaba and Campina Grande, and around 7.0 for Peru, Ishigaki (a line growing naturally across the Islands), K-8, and Cunningham. However, the range of pH which allowed fairly high dry matter production was different with different lines: K-8 showed the widest range, whereas Ishigaki showed the narrowest range. These results indicate that Ishigaki, Peru, and Cunningham are suitable for growing in neutral to slightly alkaline Rhodualfs, while Campina Grande, Piracicaba, and K-8 for slightly acid to neutral Rhodualfs[14].

3) Soil salinity tolerance

As the strong monsoon wind carries seawater splashes on to the Ryukyu Islands, soil salinity is very high in windward pastures, especially during the winter season[15]. Yield stability of pasture in windward areas largely depends upon the physiological tolerance to soil salinity. Therefore, nine tropical legumes including leucaena were grown in potted soil with different soil salinity ranging from 0.25 to 2.5 $mS^{-1} \cdot cm^{-1}$ (Electro-conductivity). The salinity was adjusted by adding sodium chloride to the soil (Rhodualfs)[7]. Among the tropical legumes tested, leucaena showed an exceptionally high tolerance to the soil salinity (Table 1).

Agronomy

1) Yield potential as related to agronomic management

Table 1. Salt tolerance levels and ranking of tropical pasture legumes estimated by utilizing the mathematical model

Legumes	Soil salinity causing nil yield (EC)	Rank	Soil salinity causing 1/2 yield (EC)	Rank	Proportion of yield variance explained by the model
Lotononis**	2.86 $mS^{-1} \cdot cm^{-1}$	3	1.22 $mS^{-1} \cdot cm^{-1}$	5	0.989
Endeavour**	2.34	6	1.28	4	0.949
Verano**	3.06	2	1.26	4	0.966
Greenleaf*	2.42	5	1.21	5	0.863
Silverleaf*	2.44	5	1.21	5	0.918
Cooper**	1.87	7	1.56	2	0.993
Siratro*	2.88	3	1.44	3	0.968
Centro*	2.52	4	1.26	4	0.870
Leucaena*	5.83	1	2.89	1	0.893

* Result obtained by fitting the data to $Y=a+bX$.
** Result obtained by fitting the data to $Y=a+bX+cX^2$.

Yield potential is one of the most important criteria in evaluation of forage crops. To know the yield potential of leucaena, the plants were grown under different agronomic management: (1) different inter-row spacing, (2) cutting for harvest was made when the plants reached different height (the cutting position was 30 cm above the ground), and (3) with or without mixed planting of a grass (napiergrass or guineagrass)[9].

The result is given in Fig. 2, which shows dry matter yield (t/ha) of edible portion and stems of leucaena of sole cropping and that combined with dry matter yield of the grass (grass dry matter is regarded as edible). The total edible DM yield was 13.0, 19.5 and 28.0 t/ha for leucaena alone, mixed with guineagrass, and with napiergrass, respectively. The increment in the total edible DM yield in the mixed cropping was caused by the grass: leucaena yield was depressed by both grasses. Plant height at the time of cutting did not significantly ($p<0.05$) influence the proportion of leucaena in the mixed cropping. The narrow spacing appears to give high percentage of leucaena.

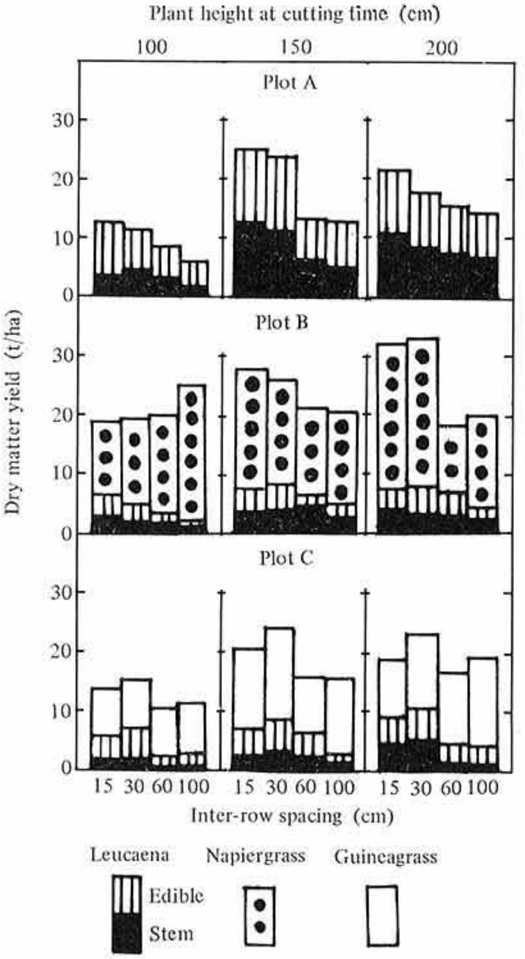

Fig. 2. Annual dry matter yield of leucaena of sole cropping (Plot A) and mixed cropping with napiergrass (Plot B) or with guineagrass (Plot C) as influenced by inter-row spacing of leucaena and height of leucaena at cutting time

The narrow spacings (15 and 30 cm) and cutting of tall plants (150 and 200 cm) generally gave high yield of the total dry matter in the mixed cropping. With leucaena alone, 15 cm spacing and cutting of 150 cm plants gave the highest yield. These yields are higher than those reported for Siratro and Stylo mix-planted with tropical grasses, but lower than those obtained from other fodder crops under intensive management in a "cut and carry" system, suggesting that leucaena/grass mixture is able to get moderately high yield of forage at lower cost than the usual forage production systems of the Ryukyu Islands.

2) *Cutting intensity*

A sand culture pot experiment was conducted to trace time courses of vegetative regrowth, nodule formation, nitrogen fixation ($C_2H_2 \rightarrow C_2H_4$), and total nonstructural carbohydrate concentration in leucaena after clipping. The result disclosed that vegetative regrowth and nitrogen fixation after clipping were influenced more strongly by differences in the residual leaf area than by the concentration of reserved nutrients in the remaining stubble. It means that the more the number of growing meristems are left, the more rapid the regrowth rates[21]. Another experiment showed that the maximum regrowth rate was obtained with clipping height of at least 30 cm and more above the ground surface[3].

Table 2. Dry matter yield (t/ha) of the Peruvian type and the naturalized type of leucaena grown in sole cropping or mixed cropping with napiergrass

Agronomic treatment	Height of leucaena at harvest (cm)					
	100		150		200	
	P	N	P	N	P	N
Leucaena in sole cropping						
Edible portion	11.5	10.2	7.7	8.9	10.2	7.6
Stems	8.7	6.8	7.3	8.6	13.8	9.3
Total	20.2	17.0	15.0	17.5	24.0	16.6
Leucaena with napiergrass						
Edible portion	7.1	2.8	5.7	2.6	8.0	2.6
Stems	5.7	1.8	5.9	2.6	12.2	3.5
Napiergrass	15.5	28.8	26.6	28.7	19.7	36.2
Total	28.4	33.4	38.2	33.9	39.9	42.3

P: Peruvian type (Peru) of leucaena. N: Naturalized (Hawaiian) type (Ishigaki) of leucaena.

3) Selection of lines

To select better lines of leucaena adapted to the given natural conditions of the Islands, a trial was made using different lines collected from abroad or in the Islands[1].

The height of an individual plant 1 year after sowing varied from 168 to 369 cm and the trunk diameter from 21 to 43 mm among the lines. Lines bred in Australia and Hawaii, viz., Cunningham, Peru, CP161227 and K-8 showed better growth. In addition, to know the growth potential as a plant community, dry matter yield of improved and unimproved lines (Peru and Ishigaki) was compared. They were grown as the sole cropping or with napiergrass[10]. The result is shown in Table 2.

The Peruvian leucaena was taller than Ishigaki by 10–20%. In the sole cropping of leucaena, dry weight of edible portion of Peru was greater than that of Ishigaki. In the mixed cropping with napiergrass, dry weight of edible portion of Ishigaki was markedly reduced.

Soil managements

1) Fertilization

The pH value of Hapludults and Rhodualfs was 4.0–5.5 and 6.0–7.2, respectively. It suggests that Hapludults require large amounts of lime and phosphorus for the normal growth of leucaena, while Rhodualfs some micronutrients[8,17,18]. In fact, a field experiment conducted on Hapludults indicated that application of 7–9 t/ha of lime increased pH of the top soil (0–20 cm) to 6.5–7.2 and phosphorus at least 150 kg/ha was minimum for increasing soil available P for the maximum growth of the tropical legumes[17]. A favorable effect of Mo application to the soil became greatest at 300–400 g/ha due to enhanced biological N_2-fixation[19]. However, tap roots of leucaena grow deep in the soil, so that large capital input is needed to improve deep soil. Therefore, it seems that the cultivation of leucaena on Hapludults is economically not feasible.

Rhodualfs, on the other hand, seem better for growing leucaena due to their pH range, provided that other soil nutrients are properly applied. Among the micronutrients, Zn at 2–3 kg and Fe at more than 8 kg/ha appeared to be most effective for the growth of tropical legumes[12,19].

2) Fertility carried over

Abundant forage production by the top of leucaena must be associated with greater production of underground systems, which, in turn, release nitrogenous substances originally derived from symbiotic N_2-fixation into soil for the following crop[14].

A field previously cropped to leucaena was

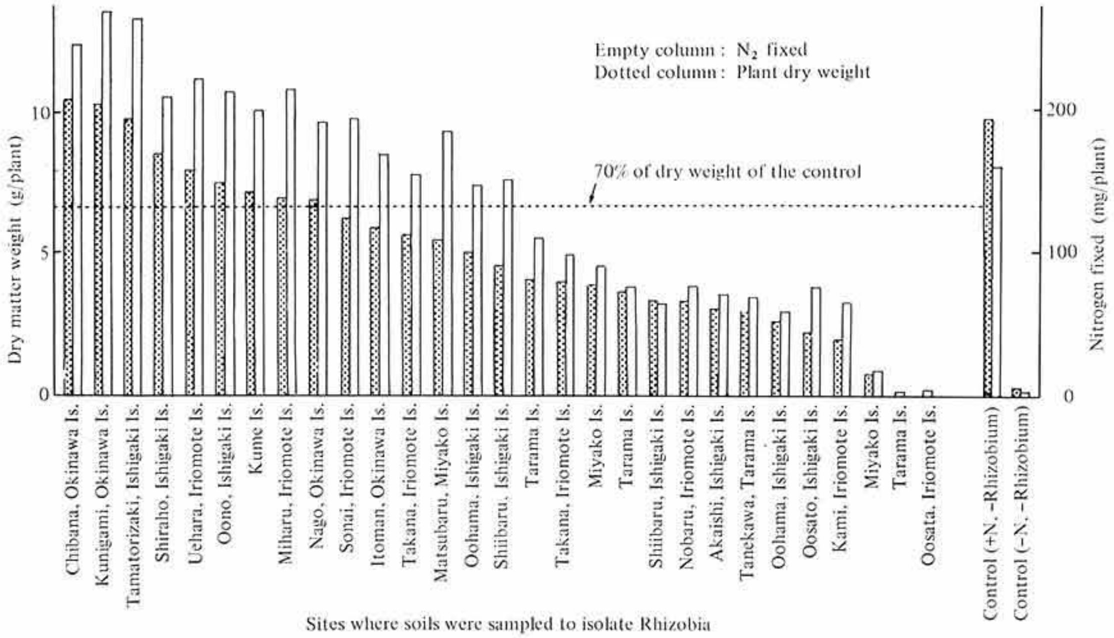

Fig. 3. Plant growth and biological N_2-fixation of leucaena inoculated with Rhizobia isolated from soils of various parts of the Ryukyu Islands
Plants were aspectically grown in the Leonard jars.

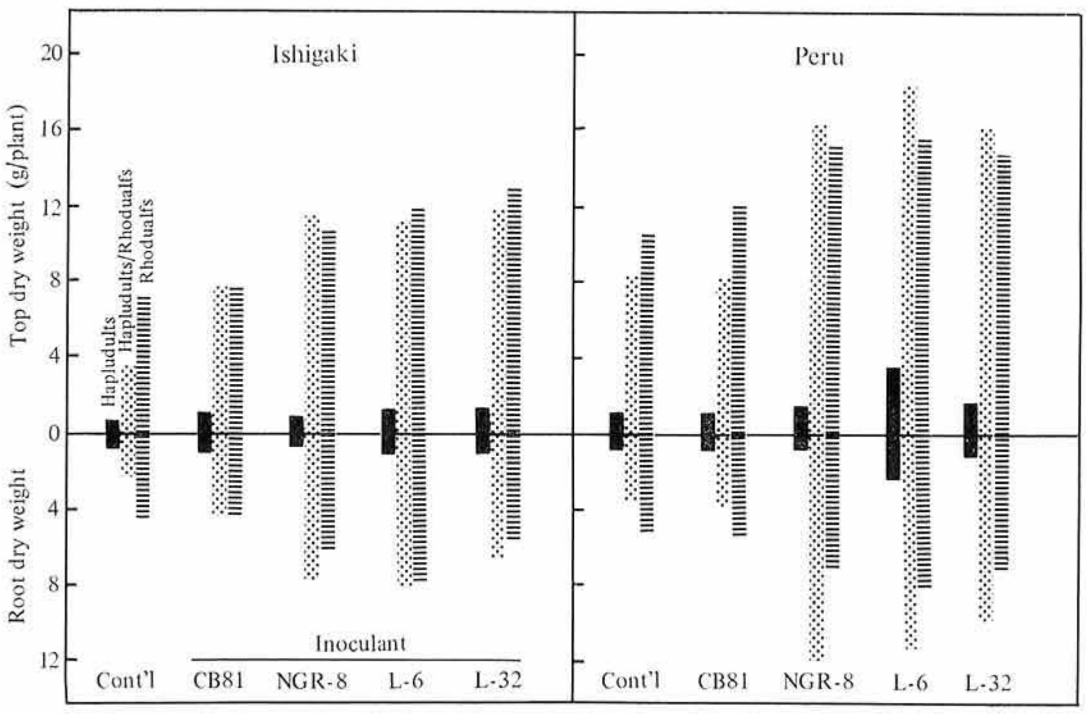

Fig. 4. Growth of leucaena as affected by soil types of the Ryukyu Islands, different inoculants and types of leucaena

planted to wheat so as to evaluate the potential of leucaena as a source of organic fertilizer in a rotational system. Although grain yields differed significantly with the preceding cropping systems of leucaena, the highest yield was obtained from the sole cropping of leucaena, followed by mixed cropping with grasses. The grain yield was highly correlated with annual dry matter yield of the preceding leucaena, showing the following equation: $Y = 0.5889 + 0.037X$, $r = 0.809$, where Y represents wheat grain yield (t/ha) and X the preceding leucaena production (t/ha)[5].

This indicates a significant role of leucaena as a source of organic N. The highest effectiveness of the residual organic matter was approximately equivalent to the application of 75 kg N/ha.

3) Inoculation

Leucaena nodulates spontaneously with indigenous soil *Rhizobia* without specific inoculation. However, nodulation with indigenous soil *Rhizobia* was not necessarily sufficient to make the leucaena productive in the Ryukyu Islands. As shown in Fig. 3, dry matter production and nitrogen accumulation greatly varied with inoculants prepared from different isolates from various places of the Islands[22], indicating that selection of effective inoculants is as important as the selection of high yielding lines. Furthermore, it was observed that a sort of compatibility exists between strains of *Rhizobia* and lines of host plants, for example, quite high productivity of Ishigaki leucaena was observed when inoculated with L-32 and Peru with L-6. This effect is also influenced by soil types (Fig. 4)[23]. Generally in the Ryukyu Islands, NGR-8, L-6, and L-32 were more effective than CB-81, which was isolated and widely used in Australia as well as other tropical countries.

Nutritive value

1) IVDMD and CP concentration

IVDMD (*in vitro* dry matter digestibility) of leucaena was comparable to that of napiergrass and considerably higher than that of other grasses extensively grown in the Ryukyu Islands. Leucaena IVDMD is near the average of tropical legumes, though the soft green portions of leucaena was included in the edible fraction analysed (Table 3)[1].

The highest annual DDM yield recorded in the Islands was 15 t/ha from leucaena/napiergrass mixed cropping, 9 t/ha from leucaena/guineagrass mixed cropping and 7.8 t/ha from the sole cropping of leucaena[9].

The crude protein (CP) concentration in the edible fraction of leucaena was about 3

Table 3. Crude protein content and *in vitro* dry matter digestibility of tropical legumes and grasses grown in the Ryukyu Islands

Species	IVDMD (%) (Expressed in equivalent to *in vitro* digestibility of goat)	CP (%)
Legumes		
Macroptilium atropurpureum cv. Siratro	61.2−73.3 (67.1)*	18.1−25.6 (21.9)*
Stylosanthes guianensis cv. Endeavour	63.1−69.9 (66.5)	14.5−18.4 (16.5)
Grasses		
Chloris gayana	40.3−66.6 (53.5)	5.3−14.4 (9.8)
Panicum maximum	46.9−64.6 (55.8)	5.1−15.0 (10.1)
Digitaria decumbens	45.3−67.1 (56.2)	5.3−13.5 (9.2)
Pennisetum purpureum	42.5−80.6 (61.6)	—
Cynodon plectotachyus	42.3−64.2 (53.3)	5.4−14.1 (9.8)
Brachiaria mutica	43.3−65.7 (54.5)	6.9−15.6 (11.2)
Setaria anceps	44.6−69.9 (57.3)	5.3−17.8 (11.5)

* Mean value.

Table 4. DHP* concentration in urine of cattle fed leucaena in southern Ryukyu Islands

Sample No.	Place sampled	Age of cattle (Month)	Leucaena fed Periods (Month)	Leucaena fed % in ration	DHP (%)	Mean±S. D.
1	Hateruma Is.	70	3	30	0.040	0.040
2	Koro Is.	38	12	30	0.140	0.351±0.280
3		72	48	30	0.140	
4		85	20	80	0.680	
5		15	12	80	0.635	
6		134	7	30	0.160	
7	Ishigaki Is.	Matured	3	30	0.315	0.185±0.171
8		Matured	3	30	0.345	
9		28	1.5	30	0.000	
10		180	1.5	30	0.080	
11	Tarama Is.	12	6	50	0.026	0.013±0.015
12		36	20	50	0.000	
13		40	30	50	0.026	
14		80	50	50	0.000	

* 3-hydroxy-4(1H)-pridone.

times higher than that of grasses grown in the Islands (Table 3). The concentration was not significantly influenced by agronomic treatments such as plant height at cutting time, plant spacings, etc. The value of leucaena was significantly higher than that of the most tropical legumes.

The highest annual CP yield (3.94 t/ha) was obtained from leucaena sole cropping followed by 2.50 t/ha obtained from leucaena/napiergrass and 2.44 t/ha from the leucaena/guineagrass. The greater reduction of leucaena yield caused by competing napiergrass was associated with the reduction of the total CP yield to the level lower than that of the mixed cropping with guineagrass, despite that the total and edible dry matter yield of napiergrass itself is very high[9].

2) DHP degrading rumen microorganism

As leucaena contains amino-acid mimosine, it is potentially toxic to livestock because mimosine is a powerful antimitotic and depilatory agent and DHP (3-hydroxy-4 (1H) pridone), a degraded form of mimosine, is a potent goitrogen[4]. However, leucaena toxicity in ruminants has not been reported in Hawaii and Southeast Asian countries possibly due to the presence of the rumen microorganism capable of degrading mimosine and DHP. Therefore, as an indirect method of detecting the existence of such microorganism, urine of the cattle fed leucaena was collected from several islands of the southern Ryukyu and subjected to DHP analysis (Table 4)[20].

DHP values of the urine collected in Tarama Island, a small island off Ishigaki, indicated possible existence of DHP degrading rumen microorganism in the cattle. The problem of isolation, culture, and practical utilization of such microorganism deserves further investigation.

Conclusion and summary

Environmental factors which might limit the growth of leucaena in the Ryukyu Islands are temperature, soil pH and soil salinity. Growth response of leucaena to these environmental factors indicated that leucaena is one of the most productive forage resources for Rhodualfs land of coastal areas in the southern part of the Ryukyu Islands.

As far as agronomic treatments are concerned, the inter-row spacing of 15–30 cm for leucaena to which napiergrass was mix-planted and harvesting when the leucaena reached 150–200 cm in height, produced the highest annual yield of usable forage. In this case, 28 t/ha of edible dry matter, 15 t/ha of digestible dry matter and 2.44 t/ha of CP, were produced. However, more yield can be expected by the application of phosphorus and some micro-nutrients such as Zn and Fe.

The yield of leucaena mentioned above is a moderately high yield of protein rich, palatable forage. More nitrogen can be obtained by the sole cropping of leucaena but additional supply of other components than nitrogen is needed to make full use of the high protein content of leucaena as the feed. Animal disorder caused by mimosine contained in leucaena is a disadvantage, but the existence of mimosine degrading microorganism in rumens was proved by an indirect method.

It is quite likely that the cost of producing forage by growing leucaena in the southern part of the Ryukyu Islands is much less than that of the present fodder cropping systems which require heavy application of N, rotational cultivation and much labor. Leucaena grown in rows interplanted with a grass seems to be the most useful forage production system in the southern part of the Ryukyu Islands, provided that the mimosine problem is solved.

References

1) Abe, J. & Kitamura, K.: Evaluation of collected leucaena. TARC-Okinawa Miscellaneous Pub. 1–4 (1983) [In Japanese].
2) Chinzei, T. & Ohya, K.: Soils and Agriculture in Okinawa. *Jpn. J. Soil Sci. Plant. Nutr.* 44, 146–156 (1973) [In Japanese].
3) Guevarra, A. B. et al.: *Leucaena leucocephala* and its nitrogen contribution to intercropped corn. Paper presented at Ann. Meeting of ASA, c-3 (1977).
4) Jones, R. J., Jones, R. M. & Cooksley, D. G.: Agronomy of *Leucaena leucocephala.* CSIRO information, Inform. Service Sheet No. 41 (4), 1–4 (1982).
5) Kitamura, Y.: Yield of wheat as affected by preceding cropping of leucaena. *JARQ*, 16, 158–160 (1982).
6) Kitamura, Y.: Leucaena. *In* Encyclopedia of Okinawa. Okinawa Times Co., Naha, 923–924 (1983) [In Japanese].
7) Kitamura, Y.: Comparative salt torelance of seven tropical grasses. *J. Okinawa Anim. Husb.*, 18, 39–45 (1983) [In Japanese].
8) Kitamura, Y.: Introduction of tropical legumes and development of legume-based pastures in subtropical Japan. *Trop. Agr. Res. Ser.*, 18, 173–185 (1985).
9) Kitamura, Y.: Potential of leucaena grown for forage production in the Ryukyu Islands, sub-tropical Japan. *Trop. Grassl.*, 19, 68–73 (1985).
10) Kitamura, Y.: The comparative yields of two types of leucaena (Peruvian v. Hawaiian) grown for forage production in Ryukyu Islands. *J. Agr. Sci. Camb.*, 106, 623–624 (1986).
11) Kitamura, Y.: Performance of tropical pasture legumes grown in Southwestern Islands of Japan. XIV. The growth of tropical pasture plants as affected by soil pH. *J. Jpn. Grassl. Sci.*, 32, 20–28 (1986) [In Japanese with English summary].
12) Kitamura, Y.: Molybdenum application to Siratro grown in Kunigami (Red-Yellow) soil. *J. Jpn. Grassl. Sci.*, 32, 143–148 (1986) [In Japanese with English summary].
13) Kitamura, Y.: Comparative salt torelance of some tropical pasture legumes. *J. Jpn. Grassl. Sci.*, 32, 160–163 (1986) [In Japanese with English summary].
14) Kitamura, Y. & Abe, J.: Comparative response of six lines of *Leucaena leucocephala* to soil pH. *JARQ*, 16, 218–223 (1982).
15) Kitamura, Y., Morita, S. & Abe, J.: Salinity problems and salt resistance of pastures. A case work on Kita Ranch in Yonaguni. *Pasture Ecol.*, 22, 5–13 (1985) [In Japanese].
16) Kitamura, Y. & Nishimura, S.: Studies on mixed cultivation of tropical legumes and grasses. X. Dry matter production and nitrogen fixation by seven tropical legumes as affected by environmental temperatures. *J. Jpn. Grassl. Sci.*, 26, 53–58 (1980) [In Japanese with English summary].
17) Kitamura, Y. & Ogata, S.: Performance of tropical pasture legumes grown in Southwestern Islands of Japan. XIII. Effects of liming and phosphorus application on the growth of tropical pasture legumes in Red-Yellow acid soil and in Reddish-Brown alkali soil. *J. Jpn. Grassl. Sci.*, 31, 59–66 (1985) [In Japanese with English summary].
18) Kitamura, Y. & Shoji, K.: Performance of

tropical pasture legumes grown in Southwestern Islands of Japan. XI. The growth response of tropical pasture legumes and grasses to phosphorus fertilizer application in Red-Yellow acid soil and Dark-Red soil. *J. Jpn. Grassl. Sci.*, 31, 67–75 (1985) [In Japanese with English summary].
19) Kitamura, Y. & Yoshino, A.: Performance of tropical pasture legumes grown in Southwestern Islands of Japan. XII. The effects of Fe and Zn application on the growth of tropical legumes in Dark-Red alkali soil and Mo and Mn in Red-Yellow acid soil. *J. Jpn. Grassl. Sci.*, 31, 225–233 (1985) [In Japanese with English summary].
20) Kitamura, Y., Ohshima, S. & Naka, K.: DHP-degradation in the cattle digestible tracts. *J. Okinawa Anim. Husb.*, 21, 34–37 (1986) [In Japanese].
21) Kitamura, Y., Samejima, M. & Abe, J.: Vegetative regrowth, nodule development and nitrogen fixation of tropical legume after harvest. I. Leucaena. *J. Jpn. Grassl. Sci.*, 27, 277–284 (1981) [In Japanese with English summary].
22) Yoshida, T., Ikeda, S. & Kitamura, Y.: A search for promising *Rhizobium* strain of leucaena indigenous to Southwestern Islands of Japan. *Jpn. J. Soil Sci. Plant Nutr.*, 58, 329–333 (1987) [In Japanese].
23) Yoshida, T., Watanabe, Y. & Kitamura, Y.: Behavior of *Rhizobium* inoculated in the rhizosphere of leucaena and its effectiveness. *Jpn. J. Soil Sci. Plant Nutr.*, 58, 323–328 (1987) [In Japanese].

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