INTRODUCTION OF TROPICAL LEGUMES AND DEVELOPMENT OF LEGUME-BASED PASTURES IN SUBTROPICAL JAPAN

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ABSTRACT

In the assessment of the economic and ecological environment of subtropical Japan emphasis has been placed on the need for introducing tropical pasture legumes and developing legume-based pastures.

Differences in plant responses to temperature, soil pH, and drought stress among introduced legume species and cultivars have indicated that sub-tropical Japan can be divided into several zones, according to the climatic and edaphic ranges within which different species may become adapted.

Yield potential and feeding value assessment in the field under representative climatic and edaphic conditions has shown that in the southern part of sub-tropical Japan *Macroptilium atropurpureum, Centrosema pubescens* and *Stylosanthes guianensis* have a potential in the hilly areas and *Leucaena leucocephala* and *M. atropurpureum* could be adapted to the lowland areas with moderately acid to alkaline soils, while in the northern part *Lotononis bainesii, Desmodium uncinatum* and *M. atropurpureum* could be adapted to the hilly areas and *D. intortum, D. uncinatum, Neonotonia wightii, M. atropurpureum* and *Trifolium semipilosum* to the lowland areas.

For developing management practices of legume-based pastures under special ranges of ecological conditions in sub-tropical Japan, the following aspects were considered: time and methods of sowing; defoliation treatments; fertilization of acid and alkaline soils; selection of companion grasses; utilization of effective strains of *Rhizobium*; and forage conservation methods.

Finally, an outline of the genotypes which should be introduced preferentially into each zone is presented.

Introduction

Beef production from a tropical legume-based pasture system requires a relatively low input of fertilizer and energy as compared to that from grass-based pastures.

The plant introduction program proposed by the Australian research workers has made a great contribution to the development of the improved legume-based pastures in the tropics.

Application and adaptation of the Australian "Concepts and Methods" to tropical pasture research are taking place successfully in a number of other tropical regions in the Americas, Africa, South-east Asia and the South Pacific (Cunningham Lab. 1964; Show and Bryan, 1976). However, the process of introduction of a large number of species and assessment of their agronomic potential as well as the incorporation of useful species into practical farming systems is an enormous task (Jones and Walker, 1983). This indicates that a standardized method of plant introduction and evaluation cannot apply to all the situations, and hence the strategies in any particular institution may differ depending upon the size of the institution, agricultural environment, etc. (Jones and Walker,1983).

In this paper I will briefly discuss our experience in the introduction of tropical legumes and the development of legume-based pastures in subtropical Japan in order to illustrate a strategy suitable for a small institution.

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General approach

The scheme for our strategy is shown in Fig. 1.

After characterizing the economic environment in which the animal production system had to be established, the target area, i.e., subtropical Japan was first divided into several zones differing in their climatic and edaphic characteristics. Then, the tropical legumes were collected and classified into several groups according to their response patterns to the environmental factors. After those procedures, the adaptation of the introduced legumes to each zone was evaluated either in experimental fields or at the farm level using a few representative species of each legume group. The principal management practices which are of particular importance for the pastures under these climatic, edaphic, and economic conditions were also developed.

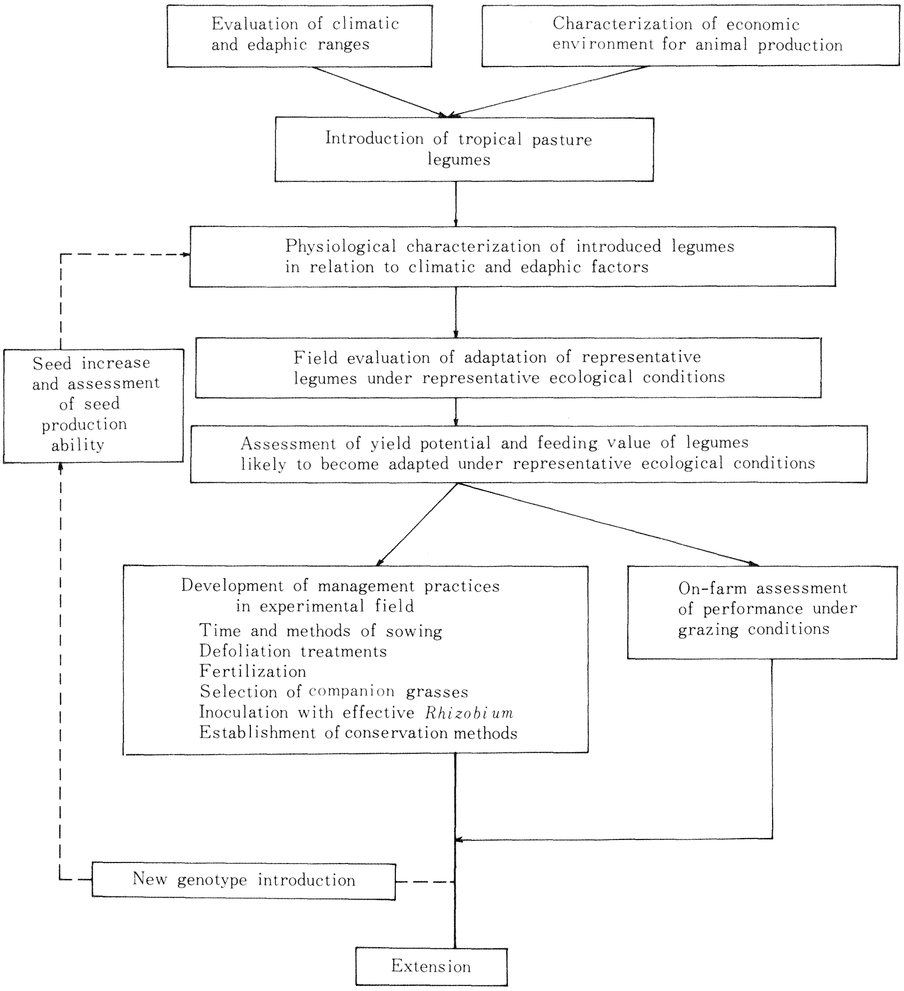

Fig. 1 Scheme for development of tropical legume-based pastures in subtropical Japan.

Prerequisites for introduction

1 Economic factors

For maximizing profits and minimizing the cost of beef production, priority should be given to the production of nutrient-rich forage with minimum agricultural inputs. This is particularly true in an area located far from the central market, such as subtropical Japan where the farm-gate prices of animal products decrease while the cost of agricultural materials required for animal production increases (Table 1 and Fig. 2).

Table 1 Farm-gate prices of animal products and agricultural materials as affected by distance from central market

Location	Approximate distance from Tokyo	Price of animal products*1		Price of agricultural materials*2	
		Beef	Calf	Concentrated feed	Urea
	(km)	(Yen/kg)	(1,000 Yen)	(Yen/20kg)	(Yen/20kg)
Okayama Prefecture	550	1,732	259.2	1,213	1,445
Miyazaki Prefecture	875	1,742	268.4	1,264	1,449
Okinawa Island	1,500	823	207.9	1,315	1,700
Miyako Island	1,800	688	200.5	1,440	1,730
Ishigaki Island	1,975	713	186.7	1,565	1,700
Kuro Island*3	2,000	556	134.9	1,600	1,700
Yonaguni Island*4	2,050	532	115.3	1,735	1,930

*1 Means of 1982. *2 Means of 1983.
*3 Irregular shipping service from Ishigaki island.
*4 Regular but infrequent shipping service from Ishigaki island.

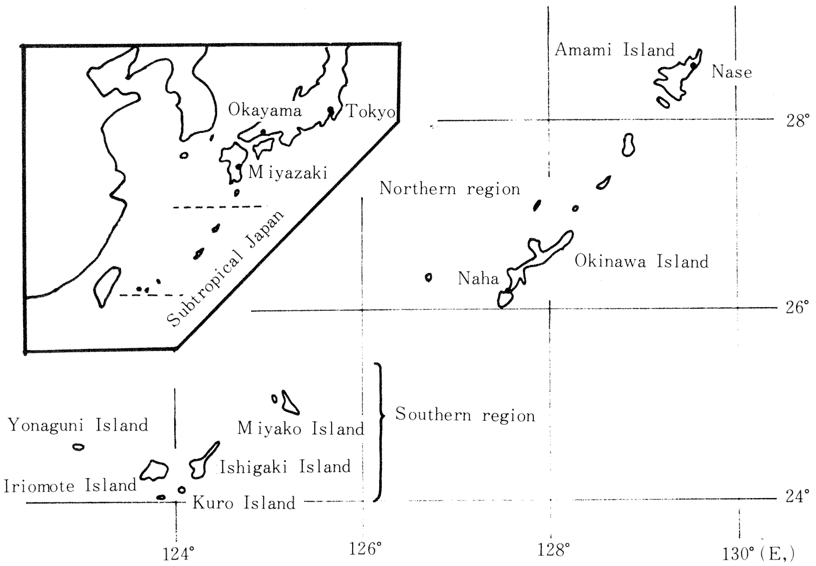

Fig. 2 Geographical location of subtropical Japan which was subdivided into a southern region and a northern region according to climatic conditions.

Since the nutritive value of tropical grasses is much lower than that of temperate grasses (Minson, 1971) even when tropical grasses are grown with nitrogen fertilizer and produce large amounts of forage the cattle fed on tropical grasses should be supplemented with concentrated feeds to meet the nutritive requirements of the animals (Minson, 1981) (Table 2).

In these assessments, emphasis has been placed on the introduction of tropical pasture legumes and the development of legume-based pastures.

2 Climatic and edaphic ranges

Temperature in the northern region (Nase, 28°30'N., 129°30'E.) fluctuates between 14.0 and 28.5°C and annual rainfall is about 3,000 mm whereas in the southern region (Ishigaki, 24° 10'N., 124°20'E.) it fluctuates between 18.0 and 29.1°C and rainfall is about 2,000 mm. The rainfall is fairly well distributed over the year in the northern region whereas summer rainfall (June to October) is scarce and unreliable in the southern region causing frequent droughts which result in yield instability of the pastures, particularly those on small islands of coral origin.

Red-Yellow soils (Hapludults) which are extremely acid (pH 4.0-5.5) predominate in the hilly areas of larger and geographically older islands (Konishi, 1965), i.e. Amami, Okinawa, Ishigaki, and Iriomote where the development of the legume-based pasture is most desirable.

Dark-Red soils (Rhodualfs), moderately acid to alkaline (pH 6.0-7.5) predominate in the coastal areas of larger and smaller islands (Matsuzaka, 1977; Oshiro and Hamagawa, 1980).

High phosphorus fixation and aluminium toxicity are commonly observed in the Red-Yellow soils (Kitamura and Ogata, 1985; Kitamura and Shoji, 1985; Kitamura and Yoshino, 1985) while the soil moisture conditions are more limiting in the Dark-Red soils particularly in the small islands (Adachi and Yokota, 1981; Mekaru, 1980; Oshiro and Hamagawa, 1980). Deficiencies in phosphorus, nitrogen, and some micronutrients such as Mo are widespread in the Red-Yellow soils whereas deficiencies in micronutrients such as Fe and Zn are widespread in the Dark-Red soils (Kitamura and Yoshino, 1985).

Table 2 Crude protein contents and *in vitro* dry matter digestibility of tropical legumes and grasses grown in subtropical Japan

Species	IVDMD % (Calibrated to *in vivo* digestibilty of goat)	CP %
Legumes		
Leucaena leucocephala	60.6—65.9 (63.2)*	24.4—26.9 (25.7)*
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.

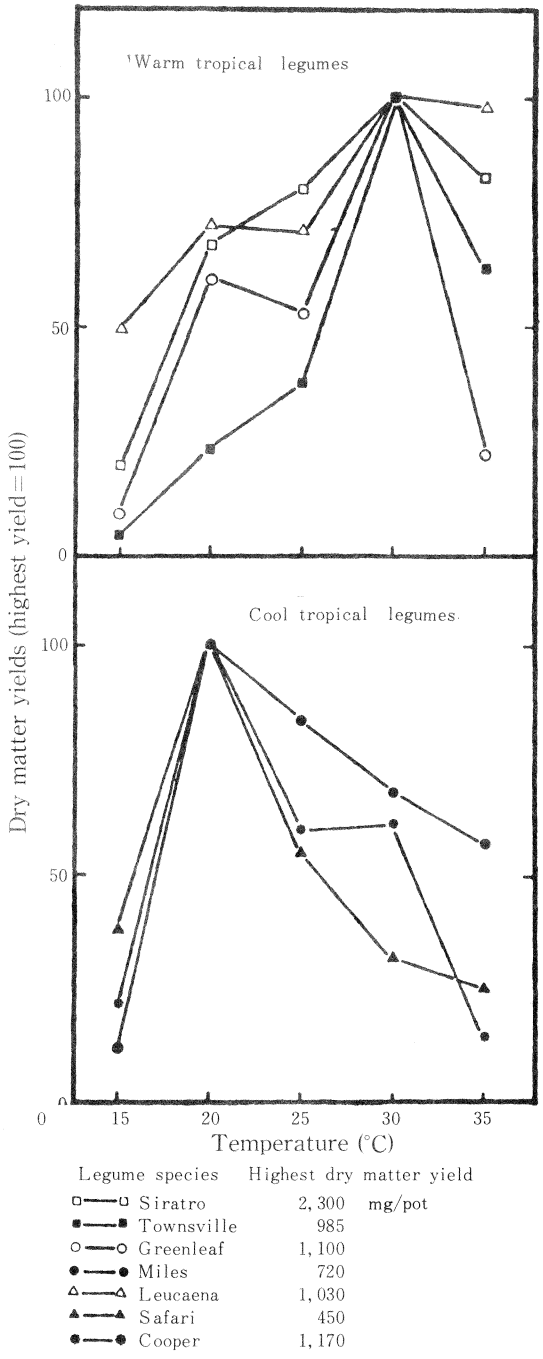

Fig. 3 Dry matter production of seven tropical legumes, as affected by environmental temperature (percentage value to the highest yield for each species).

Physiological evaluation of introduced legumes

The characteristics of the introduced legumes were first evaluated in relation to growing temperature, soil pH, and soil moisture level which are most likely to limit the adaptation of legumes in subtropical Japan.

1 Optimum temperature for growth

Earlier work had shown the presence of two groups of tropical legumes in relation to their response to air temperature, i.e., warm tropical and cool tropical legumes (Sweeny and Hopkinson, 1975). Therefore a phytotron experiment was carried out to define more accurately the optimum temperature for growth (Fig. 3). The results showed that *Neonotonia wightii, Desmodium* spp., *Lotononis bainesii, Trifolium semipilosum* and subtropical cultivars of the *Medicago* spp. belong to the cool tropical legume group while *Stylosanthes* spp., *Macroptilium atropurpureum, Centrosema pubescens* and *Leucaena leucocephala* belong to the warm tropical legume group (Kitamura and Nishimura,1980). The optimum temperature for the former group was 18 to 26°C and for the latter goup 25 to 33°C, respectively. We also found that the range of optimum temperature for some legumes such as *M. atropurpureum* was wider than for others such as *T. semipilosum.*

2 Response to soil pH

Although available information implies that the soil calcium and pH values most likely affect nitrogen fixation directly whereas aluminium and manganese seem to inhibit the growth of host plants (Munns, 1976), these effects can be measured by quantitative analysis of plant dry matter or nitrogen production.

Fig. 4 illustrates the results of a pot experiment in which ten tropical legumes were

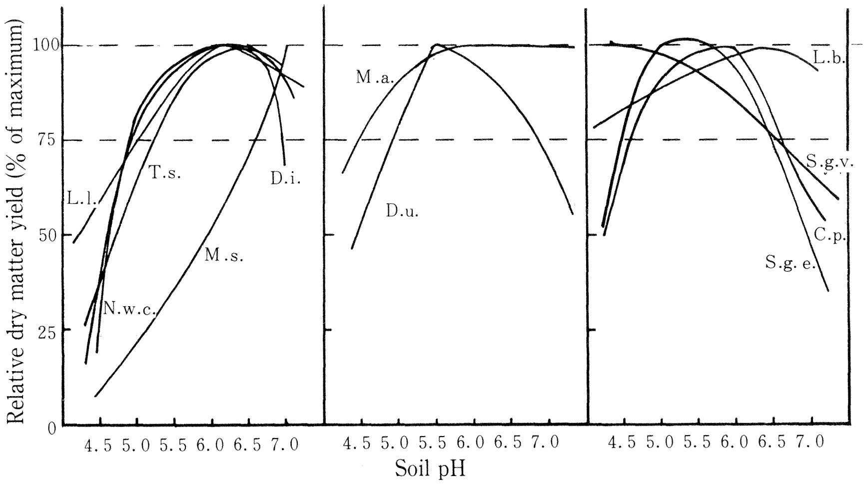

Fig. 4 Response patterns of tropical pasture legumes to liming on Red-Yellow soils of subtropical Japan.

Key to species identification :

C.p. -*Centrosema pubescens*. D.i. -*Desmodium intortum* cv. Greenleaf
D.u. -*Desmodium uncinatum* cv. Silverleaf
L.b. -*Lotononis bainesii* cv. Miles, L.l. -*Leucaena leucocephala*
M.a. -*Macroptilium atropurpureum* cv. Siratro.
N.w.c. -*Neonotonia wightii* cv. Cooper, N.w.t. -*Neonotonia wightii* cv. Tinaroo (Fig. 5)
S.g.e. -*Stylosanthes guianensis* cv. Endeavour, S.g.v. -*Stylosanthes hamata* cv. Verano
S.g.s. -*Stylosanthes guianensis* cv. Schofield (Fig. 5)
T.s. -*Trifolium semipilosum*. M.s. -*Medicago sativa*

grown in pH gradients ranging from 4.5 to 7.0 after the addition of calcium carbonate to Red-Yellow soils (Kitamura, 1985). Some of the Hawaiian results are also presented (Munns, 1976).

Introduced tropical legumes appeared to tolerate soil acidity better than their temperate counterparts suggesting that tropical legumes in general show a natural adaptation to severely leached tropical soils with low base status. It was also revealed that the range of species adaptation to soil acidity and species response to liming shows conspicuous variations even among tropical legumes.

Judging from the lime application level required to increase the yield, tropical legumes fall into the following three groups in terms of their adaptation to soil acidity.

1) Species which are not adapted (not more than temperate species) -*L. leucocephala, T. semipilosum,* and a subtropical cultivar of *Medicago.*
2) Species that are adapted-*N. wightii, D. intortum* and *uncinatum*, and *M. atropurpureum*.
3) Species showing a high degree of adaptation-*L. bainesii, C. pubescens,* and *S. guianensis.*

3 Drought sensitivity

Yield stability of the pastures developed in the small islands of the southern region largely depends upon the drought tolerance at the cellular level. Avoidance mechanism may be simply considered in terms of factors which increase the supply of water to the plant and the factors which restrict water output (Humphreys, 1981).

In this sense we compared drought sensitivities of introduced tropical legumes (Kitamura *et al.*, 1983) and distinguished three groups of tropical legumes in terms of their drought avoidance mechanism under drought stress, i.e., the legumes in which:

1) Factors restricting water output operate first and factors increasing water input operate subsequently,
2) Both factors act at the same time, and
3) Factors operate in the opposite way to (1).

The species in group (3) including *M. atropurpureum, S. guianensis* and *humilis,* and *Leucaena leucocephala* showed a better adaptation to drought stress.

Zoning and allocation of introduced legumes.

With regard to both the climatic and edaphic ranges and the response patterns of the

Table 3 Classification of subtropical Japan into five zones by air temperature ranges, soil pH ranges, and soil moisture levels during drought periods

	Dividing factor			Legume species that can be adapted
	Temperature	Soil pH	Soil moisture	
Subtropical Japan	Northern region	1 Hilly area		1 Siratro, Lotononis, Greenleaf *Desmodium* etc.
		2 Lowland area		2 Silverleaf *Desmodium*, Kenya-white clover Medics, Cooper *Neonotonia*, etc. .
	Southern region	3 Hilly area		3 Siratro, Centro, Stylo, etc..
		Lowland area	4 Wet part	4 Siratro.
			5 Dry part	5 Siratro, *Leucaena,* etc.

introduced legumes to the environmental variables, subtropical Japan may be divided into several zones within which each introduced legume is well adapted to the temperature, soil pH, and soil water level during drought periods, as shown in Table 3.

Field evaluation

Yield potential and feeding value of the legumes grown in the field were evaluated on the basis of these criteria. Such a procedure should be adopted before releasing legumes at the farm level.

1 Adaptation to field conditions and yield potential

A small sward cutting trial on a few representative cool and warm groups of tropical legumes was conducted either in the northern region (Anonymous, 1984) or in the southern region (Kitamura, 1981, 1983b).

The results of the experiments showed that the seasonal variations of yield affected the total annual yield. Tropical legumes of the warm group gave a significantly lower yield than the tropical legumes of the cool group from October to May when grown in the northern region, while the growth of the tropical legumes of the warm group ceased from July to September, the period corresponding to the highest day/night temperatures in the southern region. The latter hardly persisted in mixed swards up to the next cool season.

These results led to the conclusion that the tropical legumes of the cool/warm group were not well adapted to the southern/northern region, respectively (Fig. 5).

An investigation on the relationship between drought sensitivity of the introduced legumes and soil moisture levels was also conducted in the experimental field established in the dry part of the lowland areas (Kitamura and Abe, 1984).

The information on the relative drought sensitivity obtained in the greenhouse experiment (Kitamura *et al*., 1983) was found to be applicable to the field conditions (Table 4) (Kitamura and Abe, 1984).

The results obtained from a greenhouse experiment (Kitamura, 1985) aimed at testing the response to soil pH were also found to be applicable to the field conditions (Table 5).

In general, yields of legume-based pastures in subtropical Japan were higher than those in other locations of the tropics but lower than the yields of grass pastures obtained after application of 30 to 50 kg nitrogen after each harvest. However, it was observed that the legume-based pastures are superior to the grass pastures in terms of economical production of protein and other digestible nutrients and high accessibility for animal intake, hence, the

Table 4 Plant top dry weight of tropical pasture legumes as affected by soil moisture levels (g/m²)

Species	Not-clipped*			Clipped*		
	Wet**	Dry**	D/W×100	Wet**	Dry**	D/W×100
Silverleaf *Desmodium*	75.7	79.9	105.5	66.3	66.8	100.8
Greenleaf *Desmodium*	115.5	60.2	48.0	54.6	26.4	48.4
Centrosema	101.0	135.1	133.8	51.0	65.1	127.6
Siratro	95.6	126.1	131.9	41.1	61.3	149.1
Tinaroo *Neonotonia*	135.7	113.6	83.7	55.2	37.6	68.1
Schofield stylo	210.6	138.7	65.9	62.0	36.3	58.5
Townsville stylo	102.0	110.8	108.6	—	72.9	—

* Plants mere clipped or not clipped at 5 cm from the ground surface one day before the irrigation.
**No water or 30 mm of water was supplied twice a week in the dry or wet treatment, respectively.

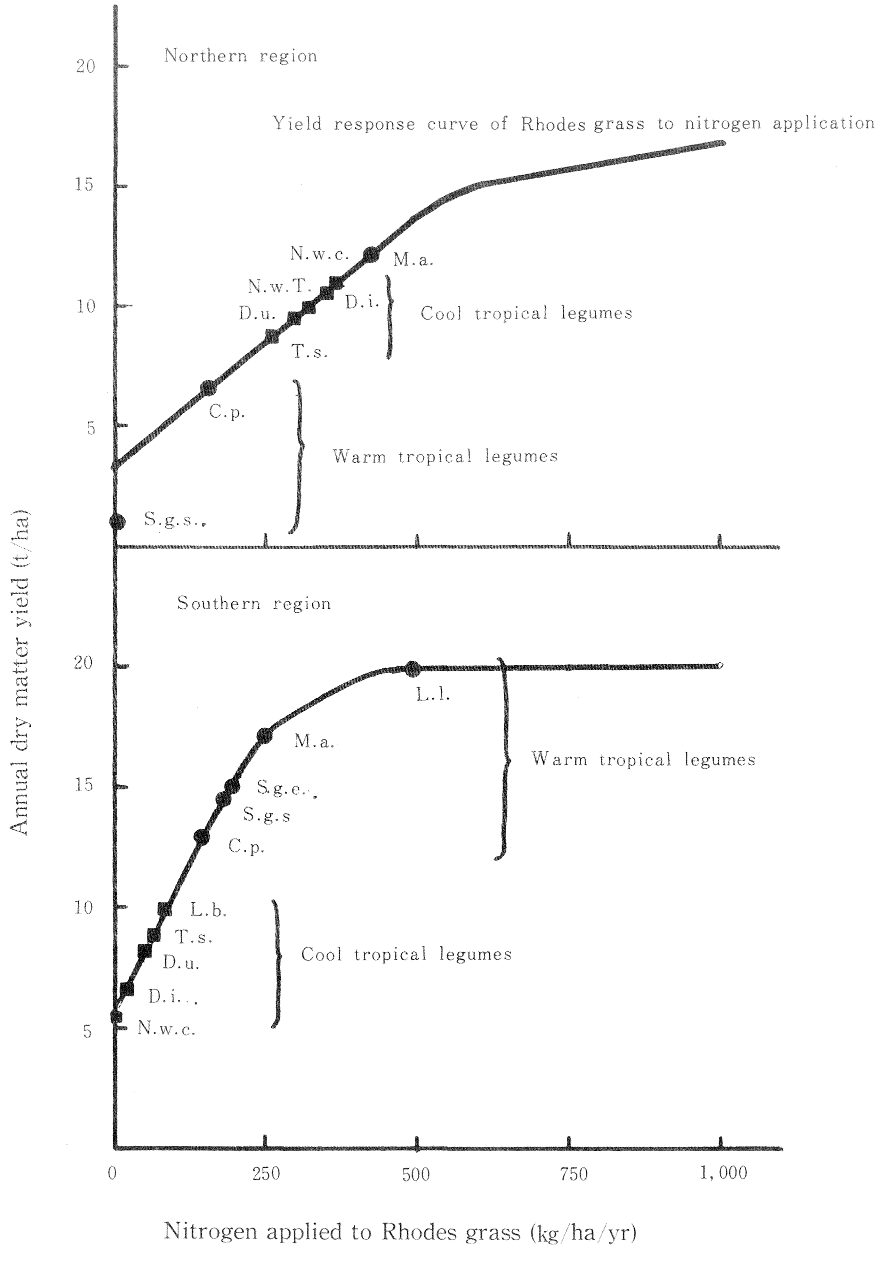

Fig. 5 **Diagrammatic comparison of yield potential of the introduced tropical legumes and Rhodes grass after nitrogen application. The legumes were grown with Rhodes grass, Guinea grass, *Setaria anceps*, or Pangola grass each and the legume-grass total yields are indicated (10 clippings/year). See fig. 4 for legends.**

Table 5 Annual dry matter yields of *Macroptilium atropurpureum* cv. Siratro and *Stylosanthes guianensis* cv. Endeavour grown in Red-Yellow soil and in Dark-Red soil with application of varying levels of phosphorus and lime

Liming (ton/ha)	Red-Yellow soil: Phosphorus application rate (kg/ha) 0	50	100	150	0	50	100	150
	(Siratro)			-kg/ha-			(Endeavour)	
0	1,500	3,750	4,200	1,950	2,720	6,650	8,250	11,730
4	3,700	4,600	4,050	6,250	1,750	6,150	9,000	8,650
8	2,900	5,900	5,120	6,650	2,150	5,050	4,650	6,050
12	1,750	5,100	5,050	5,100	3,300	4,550	4,480	4,250

Liming (ton/ha)	Dark-Red Soil: Phosphorus application rate (kg/ha) 0	30	60	90	120	0	30	60	90	120
0	10,710	11,250	11,820	11,310	11,100	6,900	6,000	6,550	7,010	5,850

low cost of beef production (Fig. 5).

2 Feeding value

Field survey indicated that the forage grasses which are routinely grown in subtropical Japan generally contain a level of crude protein of less than 6.5 % except during the low productive cool seasons (Kitamura, 1984b). In contrast our experiments showed that the nitrogen content in *M. atropurpureum* cv. Siratro exceeded 3.0% (18.8% CP) and was less affected either by the growing seasons or by the cutting intervals than that of grasses (Kitamura, 1983a, 1984a).

Annual yield of crude protein associated with biological nitrogen fixation of the generally adapted legumes ranged from 130 to 370 kg per ha per year in the southern region (Kitamura, 1983a, 1984a), while that in the northern region was slightly lower (Anonymous, 1984). Farm managers must apply nitrogen fertilizer at the rate of 600-800kg N per ha per year in order to obtain such levels of crude protein from their grass pastures in subtropical Japan (Kitamura, 1983a, 1984a).

It was also shown in the field survey that *in vitro* dry matter digestibilities of the forages fed to the cattle of Ishigaki Island ranged from 40.9 to 54% (Uchida and Kitamura, 1983), whereas those of *M. atropurpureum* and *S. guianensis* ranged from 61.2 to 73.0% and 63.1 to 69.6%, respectively, in our experiment (Kitamura, 1983a, 1984a). Those ranges of IVDMD % were less affected by the growth seasons and the advance of maturity as compared to those of grasses. Annual digestible dry matter yields obtained from the mixtures of *M. atropurpureum, S. guianensis,* and *L. leucocephala,* each mixed with a grass, were equivalent to the nitrogen application of 350 to 500 kg per ha per year to Rhodes grass pastures. Percentages of IVDMD of the companion grasses were also improved compared with those of the grasses fertilized with moderately higher levels of nitrogen (Kitamura, 1983a, 1983b, 1984c).

Management practices

In addition to the introduction and evaluation programs of tropical legumes, it is essential in subtropical Japan to show to the farmers which management practices may influence the potential yield of the legumes sown under the climatic and edaphic conditions of a region, because farm managers are not accustomed to growing tropical legumes and the experience gained in the temperate zone can seldom be successfully applied. These practices include time and methods of sowing, defoliation treatments, selection of the associated grasses, inoculation with effective *Rhizobium* strains, soil fertilization methods, and conservation methods of harvested forages (i.e., Kitamura and Tanaka, 1984).

On-farm observation

As a follow-up of the evaluation programs, several farmers in Ishigaki Island were asked to incorporate tropical legumes into their pastures and to test the performance under grazing conditions or cutting system either on hilly areas with acid soils or lowland areas with moderately acid to alkaline soils.

Based on the data obtained, it was shown that *S. guianensis* is well adapted to hilly areas but not to lowland areas probably due to the high soil pH. *M. atropurpureum* was well adapted to either areas but thrived best in lowland areas with moderately acid and well drained soils. Peruvian *Leucaena* yielded about 1.5 fold more dry matter than Hawaian-*Leucaena* in the lowland areas. With defoliation treatments, Stylo persisted very well, while Siratro died out under the grazing conditions prevailing in the area, but showed excellent performance in the cut-and-carry system. Stylo tended to show a high mortality in the lenient cutting treatments.

New genotype introduction, research priorities and general conclusions

Based on the results of introduction and evaluation of tropical legumes it was found that the tropical legumes introduced offer a potential for the development of an economical beef production system in subtropical Japan. It was also concluded that problems must be solved in the near future either by the introduction of new genotypes which will be more extensively adaptable to the climatic and edaphic conditions of subtropical Japan or by further research in several fields.

The main conclusions are as follows:

A Priority should be given to the introduction of new genotypes of the following species in the immediate future;

1 *Stylosanthes* spp. which are adaptable to the lowland areas with alkaline soils in the southern region and to the northern region with cool temperature or frost in the northernmost part.

2 *Leucaena leucocephala* which can grow in acid soils and in the northern region.

3 *Macroptilium atropurpureum* in which rooting systems are readily established and growth points are located at the basal part so that better persistence under grazing conditions can be expected.

4 Creeping legumes which are able to withstand the high temperatures of the southern region.

B Priorities in research should be directed to the following;

1 Studies on animal production under grazing conditions and economic comparison with original grass pastures.

2 Introduction and evaluation of a wider range of companion grasses.

3 Studies on more extensive fertilization practices including micronutrients for the maintenance of legume dominance, particularly on Red-Yellow soils.

4 Selection of effective *Rhizobium* in the extremely acid soils.

5 Establishment of forage conservation methods particularly suited to the tropical legumes.

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Discussion

Cocks, P.S. (ICARDA), **Comment:** When legumes are tested under grazing they should give better liveweights than grasses, presumably due to factors such as the better quality of the proteins contained in the legumes or the balance between protein and energy.