LEGUMINOUS PLANTS IN TROPICAL PASTURES*

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ABSTRACT

The Australian philosophical and practical approach to research problems in the establishment and maintenance of mixed legume-grass pastures under tropical conditions is outlined. An understanding that legumes originated in the tropics is basic to successful studies in plant nutrition and rhizobial inoculation of tropical pasture species. The most important factors in success with tropical legumes are (a) the establishment of a fully effective symbiosis, (b) the provision of adequate plant nutrition for the symbiosis to function and the plant to grow well, and (c) the imposition of a grazing regime that allows the legume to persist while still contributing nitrogen. Greatest emphasis is laid on plant nutrition, particularly phosphorus nutrition, for countries where research on tropical grazing legumes is beginning.

INTRODUCTION

It is no longer necessary to make a case for the ability of tropical legumes to fix nitrogen. In the past 20 years abundant evidence of this has been advanced (Henzell and Norris 1962, Henzell 1967, 1968). One of the most striking examples was that of Moore (1962) at Ibadan, who showed that *Centrosema* in association with giant stargrass (*Cynodon plectystachyum*) contributed 280 kg/ha (250 lb/ac) of N per annum to the soil and raised the N content of the associated grass from 1.8% to 2.4%. We must now make up our minds how best to exploit the ability of tropical legumes to fix nitrogen under a grazing regime. The outstanding value of a legume-grass association for grazing rests on a property of the legume pointed out by Haydock and Norris (1967), that is the constancy of its nitrogen percentage. In a pure grass pasture, whether fertilized with nitrogen or not, the nitrogen percentage may go up and down within wide limits, and may frequently fall below maintenance level for animals despite the presence of large amounts of forage. By contrast the N percentage of a legume, over a very wide range of effectiveness of its associated rhizobia, reaches a level characteristic of the species and remains there. The more effective the rhizobial strain the more dry weight is produced, but the protein content stays the same, and is normally adequate for animal nutrition. This presupposes of course that there are no plant nutrient deficiencies limiting N fixation, as discussed below.

THE AUSTRALIAN TROPICAL PASTURE LEGUME SITUATION

Intensive work on the incorporation of legumes into pastures in tropical northern Australia has developed since about 1950. Excellent reviews of this work have been published by Henzell (1967), Hutton (1968) and Hutton (1970). With few exceptions the native leguminous species of Australian tropical areas are insignificant contributors to animal nutrition, or respond only slightly to applied fertilizer, so that almost the whole pasture development programme is based on species introduced from overseas. This is in striking contrast to regions such as Central America or parts of South America where the native pasture is abundantly furnished with legume species in such genera as Desmodium, Phaseolus, Centrosema,

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TABLE 1

Tropical pasture legumes used commercially in Northern Australia (from Henzell 1967)

Species	Common names of commercial cultivars	Place of origin[1]
Calopogonium mucunoides	Calopo	Probably South America
Centrosema pubescens	Centro	Probably South America
Desmodium intortum	Greenleaf Desmodium	Central America
Desmodium uncinatum	Silverleaf Desmodium	Brazil
Dolichos axillaris	Archer Dolichos	Kenya
Dolichos uniflorus	Leichardt Dolichos	Asia
Glycine wightii	Tinaroo, Cooper, Clarence, Yatesco Glycine	Africa
Leucaena leucocephala	Hawaii, Peru, El Salvador, Leucaena	Central and South America
Lotononis bainesii	Miles Lotononis	Southern Africa
Phaseolus atropurpureus	Siratro	Mexico
Phaseolus lathyroides	Phasey Bean	Probably Central America
Pueraria javanica	Puero	Asia
Stylosanthes humilis	Townsville Stylo	Probably South America
Stylosanthes guyanensis	Schofield and Fine-stem stylo	South America
Vigna luteola	Dalrymple Vigna	Costa Rica

[1]Place of origin of the commercial cultivars. The species as a whole may have a wider natural distribution.

Stylosanthes, Zornia and Alysicarpus, to name but a few, even if the grazier may be unaware of their existence. Table 1 (from Henzell 1967) shows the origins of tropical pasture legumes that have reached the stage of commercial exploitation in Australia.

Seedsmens' lists for 1970 offered seed of eighteen species or cultivars of tropical legumes at prices ranging from A$0.24 per kg ($0.11 per lb) for *Dolichos uniflorus* to A$18.08per kg (A$8.20 per lb) for *Lotononis bainesii.* Inoculant peat cultures for all these legumes were also available from seedsmen at standard prices of A$0.68 for small (70g.) or A$1.36 for large (130g) cultures.

The search for new species, which began with the establishment of the C.S.I.R.O. Plant Introduction Service in Canberra in 1929, continues actively, both at Federal and State level. Bryan (1963) indicated large gaps in the lists of potential introductions in such promising genera as Desmodium, and over the last 20 years there have been a number of plant explorations in search of material. Following the outstanding success of the annual *Stylosanthes humilis* (Townsville stylo—formerly Townsville lucerne) in the monsoonal northern areas with a long dry season (Humphreys 1967) intensive interest has recently focussed on this genus. Over 200 introductions in 14 species are under examination, and since there is evidence of strain specificity in this genus the whole collection is also being screened in my laboratory for rhizobial reaction, so that effective inoculants may be supplied if required.

The rhizobial aspect of tropical pasture legumes has been under close examination by both C.S.I.R.O. and Queensland Department of Primary Industries for some 15 years (Norris 1970). To some extent a *Rhizobium* introduction service has run parallel to the plant introduction service. Satisfactory inoculant strains have been selected for each legume in commercial use, and a pool of *Rhizobium* material built up for future screenings. The C.S.I.R.O. culture collection at present contains about 1100 strains from tropical species. Selected strains are passed on to the Australian Inoculant Research and Control Service (AIRCS—formerly known as U-DALS), which in turn issues them to inoculant manufacturers (Date 1969), of which there are at present four operating in Australia.

Some idea of the intensive interest in tropical pasture development in Australia may be gained from the fact that in Queensland alone there are at present 45 research scientists in a number of disciplines in the Division of Tropical Pastures of C.S.I.R.O., and 85 pasture research and extension workers in the Queensland Department of Primary Industries. Since 1950, when there was virtually none, the area of improved pastures based on perennial tropical legumes has grown to approximately 321,570 ha (794,000 ac.) and of the annual Townsville stylo to approximately 107,325 ha (265,000 ac.) in 1970 (Anon. 1970 and personal communication, Dr. J. Ebersohn). Large areas of lucerne are not counted in tropical pastures.

THE ORIGINS OF TROPICAL LEGUMES

At this point it is pertinent to refer to the evidence that the tropical legume is the original and typical one, the temperate legume the derived type. Since raising the issue in 1956 I have repeated it a number of times (Norris 1956, 1958a, 1959, 1964, 1965, 1966a and b, 1967, 1970). There are still however many pasture agronomists who seem unaware of the situation and who persistently regard *Trifolium* and *Medicago* species as setting a pattern which must be followed by tropical legumes for pasture purposes. In turn many legume bacteriologists persist in regarding *Rhizobium trifolii* as the norm, setting a pattern which must be followed by the "cowpea type" rhizobia common to tropical species. This has some unfortunate repercussions for inoculation practice.

The data of Taubert (1894) indicate that 82% of genera and 52% of species of the legumes known at the time are tropical. A modern count would probably not alter this greatly. The large number of small genera occurring in tropical regions are a reflection of relic status. Many of the genera in the most primitive sub-family, *Caesalpiniaceae* are of this type, continuing to inhabit the environment described by Tutin (1958) as "that of the monkey, macaw, parrot and fruit-eating bat".

From the original unspecialised jungle tree form the morphological specialisation of the legumes has been from jungle liane to perennial creeping forms to annual herbaceous forms, and the physiological specialisation of the development of cold and drought tolerance (including escape mechanisms such as annual habit). A recent numerical survey of the legumes of Africa by Brenan (1965) showed 66.6% of endemic genera in *Caesalpiniaceae* as against 36.4% in *Mimosaceae* and 26.9% in *Papilionaceae,* which he cautiously suggests is "perhaps to be taken as an indication that the *Caesalpiniaceae* are phylogenetically the most primitive of the three. He also points out that the number of endemic genera is very much greater in the rainforest that in the savannahs, and that the majority of the savannah endemic genera are in the most specialized sub-family, *Papilionaceae.*

The aspect of specialisation that concerns the legume bacteriologist is specialisation in receptivity towards *Rhizobium.* In my view (Norris 1956) there is good evidence for regarding the ubiquitous slow-growing tropical "cowpea type" *Rhizobium* as the archetype from which all other types are derived. A common characteristic of legumes with "cowpea" *Rhizobium* is promiscuity, that is ability to nodulate effectively with a wide range of rhizobial strains. From this unspecialised condition progressive physiological specialisation of the legume has led to selectivity for *Rhizobium* strains or "strain specificity" giving rise to the "cross-inoculation groups". Further to this, great changes have occurred in the *Rhizobium* itself. Based on comparative study of a large *Rhizobium* collection, Norris (1965) showed that the "cowpea type" rhizobia (61% of the collection examined) produce alkaline end-products during growth, probably by splitting ammonia from nitrogenous compounds, but rhizobia associated with legume groups which has adopted alkaline soils are acidproducers. The hypothesis advanced is that the alkali-producing habit confers survival value in acid soils but loses its survival value in alkaline soils. Under alkaline conditions acid-production is of no consequence since it is taken care of by the soil, but the fast growth which accompanies acid production gives strong competitive advantage against other soil micro-organisms. The classical examples of pasture legumes where both legume and *Rhizobium* are adapted to alkaline soils are the genera *Trifolium* and *Medicago*, particularly the latter. The most important of the tropical forages to have made this change is *Leucaena leucocephala* (see below).

IMPORTANT FACTORS IN SUCCESS WITH TROPICAL LEGUMES

These may be listed in order of priority as: (a) establishment of a fully effective symbiosis (b) provision of adequate plant nutrition for the symbiosis to function, and the plant to grow well (c) imposition of a grazing regime that allows the legume to persist and contribute nitrogen.

(a) *An effective symbiosis*

If this is not quickly established the legume has no chance of competing with vigorous tropical grasses, being inherently inefficient at competing for soil nitrogen. Vallis *et al.* (1967), using 15N in tracer studies, showed that Rhodes grass (*Chloris gayana*) took up about 20 times as much N as associated Townsville stylo during the first 9 weeks and about 9 times as much between 9 and 13 weeks from sowing. Henzell *et al.* (1967) in a similar study of Siratro and Rhodes grass showed that Siratro obtained 1/3 of the N and Rhodes grass 2/3. Under low N conditions the small yellow legume plants will be rapidly grazed out or overshadowed by the grass, and even under good conditions of soil N the competitive depression by the grass is severe.

The advantages of symbiotic promiscuity in this respect are obvious. This is a major reason for the outstanding succcess of the two legumes Siratro and Townsville stylo in Australia (another being their great seeding ability). The degree of specificity of the common tropical legumes is shown in Table 2 (from Norris 1967).

If strain specific legumes are to be introduced to new regions success is dependent on a supply of reliable inoculant culture. However the mere selection of a strain for high N-fixing capacity is not enough. It must be followed by field trials to check that it is adapted to the common soil conditions where it will be used. The importance of this factor has just been strikingly recorded in my laboratory in Brisbane with *Leucaena leucocephala.* The *Rhizobium* strain NGR8, isolated in New Guinea, is at present incorporated in commercial inoculants, but serious nodulation failures in *Leucaena* sowings have been recorded on acid soils over several seasons. In Table 3 are shown the results of a trial in which the acid-producing strain NGR8 was compared with a slight alkali-producing strain CB81 on a soil of pH 5.0, seedlings being dug and assessed for nodulation at 8 weeks. Strain NGR8 was capable of producing nodules only with the aid of a lime pellet, but strain CB81 produced nodules even when inoculated using only sticker. Wu (1964) in Taiwan also recorded that *Leucaena* gave strong responses to inoculation, liming and molybdenum application on acid soils. The fact that *Leucaena* is a specialised species that tends to occur most naturally on limestone soils in the tropics is just beginning to be acknowledged by agronomists.

Useful techniques for selecting, testing and maintaining rhizobia are described by Norris (1964) and Vincent (1970). Date (1968 and 1970) discusses the factors affecting survival of inoculant bacteria on seed, production of nodules by the plant, and the methodology of inoculant control service and Roughley (1970) describes the preparation and use of modern seed inoculants.

TABLE 2

A guide to inoculum and lime requirement of legumes used in tropical pastures (from Norris, 1967)

Species	Common name	Expected lime response	Inoculum requirement
Calopogonium mucunoides	Calopo	No	Cowpea*
Centrosema pubescens	Centro	No	Specific
Desmodium intortum	Greenleaf Desmodium	No	Desmodium
Desmodium uncinatum	Silverleaf Desmodium	Rarely, in extreme conditions	Desmodium
Dolichos axillaris	Archer dolichos	No	Cowpea*
Dolichos biflorus	Leichardt dolichos	No	Cowpea*
Dolichos lab lab	Rongai dolichos	No	Cowpea
Glycine wightii	Cooper, Clarence or Tinaroo glycine	Occasionally at pH below 5.5	Cowpea
Leucaena leucocephala	Peruvian leucaena	Yes	Specific
Lotononis bainesii	Miles lotononis	No	Specific
Medicago sativa	Lucerne	Yes, lime is obligatory if pH is 5.5 or lower	Lucerne
Phaseolus atropurpureus	Siratro	No	Cowpea*
Phaseolus aureus	Golden gram	No	Cowpea*
Phaseolus lathyroides	Phasey bean	No	Cowpea*
Phaseolus mungo	Mung bean	No	Cowpea*
Pueraria phaseoloides	Tropical kudzu	No	Cowpea*
Stylosanthes guyanensis	Schofield stylo	No	Cowpea*
Stylosanthes guyanensis	Oxley fine-stem stylo	No	Specific
Stylosanthes humilis	Townsville stylo	No	Cowpea*
Trifolium repens	White clover	Yes	Clover
Trifolium semipilosum	Kenya white clover	Yes	Specific
Vigna luteola	Dalrymple vigna	No	Cowpea*
Vigna sinensis	Cowpea	No	Cowpea*

*Indicates a promiscuous species which will normally nodulate from native cowpea *Rhizobium* even if not inoculated.

TABLE 3

The comparative nodulation performance of Leucaena leucocephala *inoculated with an acid and an alkali-producing strain of* Rhizobium *in a soil of PH5.0*

Rhizobium strain	Method of inoculation	Per cent plants nodulated		Mean nodules per plant	
		Planted after 1 day storage	Planted after 28 days storage	Planted after 1 day storage	Planted after 28 days storage
CB81	No inoculation	Nil	Nil	Nil	Nil
An alkali-producer	Newly inoculated just before sowing	25	43	0.82	1.37
	Inoculated with sticker* only	19	1	0.36	0 02
	Lime pelleted	33	25	0.81	0.61
NGR8	No inoculation	Nil	Nil	Nil	Nil
An acid-producer	Newly inoculated just before sowing	1	Nil	0 01	0 07
	Inoculated with sticker only	1	Nil	0 01	Nil
	Lime pelleted	31	23	0.77	0.53

* 4% "Methofas" (methyl cellulose).

In Australia the basal recommendation for inoculating seed is by water slurry, that is by mixing the peat inoculum with water and thoroughly wetting the seed with the mixture, no other additives being used. However since about 1960 there has been an increasing use of lime pelleting for the establishment of *Trifolium* and *Medicago* species on acid soils where they would not normally nodulate after simple slurry inoculation. Most seedsmen offer a pelleting service for an added cost of approximately 11c per kg (5c per lb) of seed. Unfortunately there has arisen a tendency to assume that because lime pelleting is such an outstanding success with clovers and medics it must be good for all legumes, and much indiscriminate lime pelleting of tropical legumes has been done. With *Leucaena* this is a good practice (see Table 3) but with tropicals having "cowpea" *Rhizobium* it is usually without effect and may occasionally even reduce nodulation. Norris (1967) has discussed the pros and cons of this matter. There are two main uses for a lime pellet (a) to protect sensitive bacteria against acid soil where they would not otherwise nodulate or against acid fertilizer during sowing and to supply at the same time calcium needed for nodulation and (b) as a means of prolonging the storage life of inoculant bacteria when holding inoculated seed for some time before planting. In the case of "cowpea type" rhizobia, which are acid tolerant, these two uses may be incompatible. An example is given in Table 4 where the results of two seasons work on *Desmodium uncinatum* are shown. A low calcium soil was chosen in which there are almost no rhizobia capable of nodulating this species, so that results are entirely a reflection of the applied inoculant.

TABLE 4

Effect of storage on nodulation from pelleted seed of Desmodium uncinatum *inoculated with* Rhizobium CB627 Mean nodules per plant are expressed as percentage of the newly inoculated treatment

	Inoculation treatment	1969 experiment		1970 experiment	
		After 2 day storage	After 28 day storage	After 2 day storage	After 28 day storage
1	Not inoculated	Nil	Nil	3	1
2	Inoculated using sticker* only	100	52	100	100
3	Lime pellet	280	21	130	19
4	Florida phosphate pellet	232	37	112	100
5	Christmas Island phosphate pellet	128	44	122	96
6	Newly inoculated before each planting	100	100	100	100

*4% "Methofas" (methyl cellulose).

Application of a lime pellet stimulated nodulation of this species when sown soon after pelleting. Andrew and Norris (1961) showed this species to be more calcium sensitive than other tropicals. However when the seed was held for one month there was a much greater decline of the inoculant under the lime pellet than when simply stuck on with the adhesive, resulting in lower nodulation than that of unpelleted seed.

Rock phosphate pelleting is now being widely used for tropicals where pelleting is needed, but, as indicated in Table 4, survival is excellent under the sticker itself without a pellet, and it is now recommended that for most purposes inoculation may be done with dilute forms of the sticker, 1-2% of methyl cellulose or 15% of gum arabic.

There is little to choose between the two common pellet adhesives, 4% methyl cellulose and 40% gum arabic. Methyl cellulose offers economy in that 4 kg does the work of 40 kg of gum arabic, but gum arabic is far more widely available, particularly in developing countries.

(b) *A satisfactory plant nutrition*

The best of inoculants is useless if the nodules formed are unable to function because of nutrient deficiencies. As a general rule tropical legume species appear to possess high efficiency of uptake or utilization of nutrients. Andrew and Norris (1961) compared the calcium uptake of 6 tropicals with 4 temperate species on a calcium deficient soil. The tropicals made reasonable growth at levels of calcium representing acute deficiency for the temperate species. This behaviour underlies the approach to liming in the establishment of tropical species. Lime dressings are rarely necessary except in soils of acute poverty and acidity, both because of this calcium efficiency of the legume, and because of the acid tolerance of the "cowpea type" *Rhizobium* associated with them. Sufficient calcium is normally available from the superphosphate dressings made at establishment.

Similar differences between species in efficiency of use of nutrients have also been shown for copper (Andrew and Thorne 1962), for phosphorus (Andrew and Robins 1969), and for potassium (Andrew and Robins 1969).

Phosphorus is undoubtedly the prime limiting nutrient in establishment of tropical pasture legumes. Its limiting nature may be unsuspected. Townsville stylo (*Stylosanthes humilis*) is a very efficient species at P uptake. It is widespread on soils of low P level and is normally established in northern Australia with no phosphate dressings or very low rates of 125-250 kg/ha. Yet in studies by Shaw, Gates and Wilson (1966), on a low fertility solodic soil great increases in N fixation were recorded in response to increasing P application. In a field experiment yield of dry matter was raised by a factor of 2.4 and yield of N by a factor of 3.3 as superphosphate equivalent was increased from 0-502 kg/ha (0-4 cwt/ac); and under the most favourable conditions of controlled environment absolute nitrogen in tops was increased 7-fold with increase of superphosphate equivalent from 0-752 kg/ha (0-6 cwt/ac).

Soils high in P are usually already pre-empted for agriculture, and pasture development is usually restricted to inherently low-P soils. The question to be asked when going into legume-based pasture development then becomes not "Should I apply phosphate fertilizer?" but "How much should I apply?" In Australia establishment rates vary from 125 kg/ha (1 cwt/ac) superphosphate with species like Townsville stylo to 1254 kg/ha (10 cwt/ac) with species like *Glycine wightii* on krasnozem soils of high P-fixing capacity, and the cost of the fertilizer is one of the prime costs of the enterprise. In countries with no phosphate fertilizer industry this cost probably represents the turning point on which a decision must be made to attempt pasture improvement or not. But in making this decision a vital point that should not be lost sight of is that P is not only essential for the legume plants themselves but also for the animals that graze them, since animal production, once protein and energy needs are met, is often proportional to P intake (Anon. 1965).

Other common deficiencies limiting the performance of the legume symbiosis are those of molybdenum, which prevents the functioning of the fixation process even in the presence of abundant nodules (Anderson 1956), and sulphur, which prevents protein build-up (Jones and Robinson 1970; Jones and Crack 1970). Both are very common in Australia, and the widespread use of molybdenized superphosphate corrects both deficiencies.

A very full account of plant nutrient effects on pasture legumes of many species is contained in the proceedings of the XIth Internat. Grassland Congress, Surfers Paradise Qld., 1970.

General aspects of the nutrition of tropical pasture species are discussed by Andrew (1965), and Andrew and Henzell (1964), and useful techniques for this work are described by Andrew and Fergus (1964). Exploratory work may be done by foliar analysis and the use of established critical values for the principal nutrients.

Critical values of P for 9 tropical species are given by Andrew and Robins (1969a), for K by Andrew and Robins (1969b), for Cu by Andrew and Thorne (1962) while Andrew and Pieters (1970) describe and illustrate in colour the symptoms of K. deficiency on *Phaseolus lathyroides, P. atropurpureus, Desmodium intortum, D. uncinatum, Stylosanthes humilis, S. guyanensis, Lotononis bainesii, Centrosema pubescens, Glycine wightii* and *Teramnus uncinatus.*

Toxicity effects of manganese must be watched for in tropical legume nutrition, the problem being more widespread than is often realized. Andrew and Hegarty (1969) give toxicity threshold manganese values in the dry matter of plant tops as *Centrosema pubescens* 1600, *Stylosanthes humilis* 1140, *Lotononis bainesii* 1320, *Phaseolus lathyroides* 840, *P. atropurpureus* 810, *Leucaena leucocephala* 550, *Desmodium uncinatum* 1160, *Glycine javanica* 560, *Trifolium repens* 650, *T. fragiferum* 510, *Medicago sativa* 380 and *M. truncatula* 560 p.p.m. The generally higher tolerance of the tropical species is noteworthy, with the exception of *Leucaena* and *Glycine*, which ties in with the adaptation of these species to better soils.

(c) *Satisfactory grazing management to produce nitrogen turnover*

The general subject of grazing management is outside my scope. However, intelligent grazing management is essential if a perennial legume is to make significant nitrogen contribution to associated grasses in a mixed pasture. Ungrazed legumes make slight contribution to associated grasses. The position is different with annuals such as Townsville stylo where there is an enforced turnover of fixed nitrogen each dry season. Henzell (1962) found that when *Desmodium uncinatum* and *Indigofera spicata* were grown in association with *Paspalum commersonii* in conditions where no return of top growth to the soil was permitted, only 1.7% of the N fixed was transferred to the grass by Desmodium and only 0.7% by Indigofera. Whitney *et al.* (1967) in Hawaii, working under semi-field conditions where dead legume tissue could return to the soil, found that Centrosema transferred 11% of fixed N to Napier grass and 6% to pangola. For *Desmodium intortum* the figures were 5% and 2.8% and *D. canum* transferred no N and even competed with the grasses for soil N.

For significant contribution of N to associated grasses, legume tissue must be destroyed, either by passing through the grazing animal, or by decay of leaf litter returned to ground, or root tissue. It is the job of the pasture agronomist to strike as neat a balance as possible between grazing pressure that will eliminate the legume and that which will produce the maximum turnover of nitrogen. An aspect of this process deserving comment is that disappointment is sometimes expressed at the pale green colour and lack of vigour of associated grasses during the first one or two years of pasture establishment, doubt being cast on the effectiveness of the legume symbiosis. The process of N turnover is slow, and the capacity of the grass to take up N is very high, as shown by nitrogen fertilizer experiments. At the maximum rate of turnover possible for the legumes an associated grass will always be well within its potential capacity to absorb N, and must therefore present an appearance of N limitation to some degree.

SOME RESEARCH PRIORITIES FOR DEVELOPMENT OF TROPICAL LEGUME-BASED PASTURES

Properly conducted plant nutrition studies are a prerequisite to the successful establishment of tropical legume-based pastures. This does not discount the vital importance of having fully effective inoculant cultures, but in initial stages these may be requested or purchased from outside sources. Modern peat-based inoculants are of high quality and may be airmailed anywhere in the world and kept satisfactorily in the refrigerator for many months. The nutrient deficiencies of the main soil types on which pasture establishment will be attempted must be explored, and for this job careful pot work is unavoidable. Since the effect of nutrients is frequently additive, exploratory pot experiments should include all known nutrients and should be of factorial design. Also because of the varying efficiency of utilization by species it is of little use to base all work on one test species. The range of species proposed to be included in pastures should be included. Following the leads established by pot trials, intelligent estimates of rates necessary for field use may be made, but there is no substitute finally for carefully conducted field experiments to verify the most economical rate of fertilizer application.

Whether or not studies in legume bacteriology should be set up is a question of the size of the research group. The Australian philosophy is that success in pasture research depends on having a sizeable team in integrated disciplines, and that progress by isolated workers is too slow and costly. If a great deal of effort is to be put into a plant introduction service with heavy emphasis on legumes then the association of a legume bacteriologist with the team becomes essential. Experience with the genus *Lotononis* may be quoted as an example. When *L. bainesii* was first brought to Australia it could not be established until its highly specific red *Rhizobium* was obtained from Africa (Norris 1958b). Subsequently *L. angolensis* was tried and found to be completely unresponsive to the inoculant for *L. bainesii,* so a further exploration for a suitable specific strain was successfully made. Finally another line of *L. angolensis,* K681, was obtained from Kitale which was completely unresponsive to this inoculant, and further introductions of rhizobia specific to K681 had to be made. It becomes evident that the genus *Lotononis* will present more and more inoculation problems as it is explored.

An obvious corollary of this situation is that, in regions where the services of a legume bacteriologist are not available, pasture development should preferably be concentrated on the use of known promiscuous species such as Siratro, or Townsville stylo or Teramnus insofar as this is possible.

Finally the desirability of unrestricted command of grazing animals should be mentioned. It is of the greatest importance that any legume-grass combination must be placed under grazing at the earliest possible stage of investigation. Data gathered in row trials or small swards under mowing are valuable but will never reveal the behaviour of the species under grazing. For this reason the pasture workers of the Division of Tropical Pastures of C.S.I.R.O. have over 3000 animals available to them at 4 research stations. The agronomist must be able if necessary to use these animals to put pressure on his pasture whatever the short term consequences to the animals. Lack of control of animals for grazing is repeatedly a stumbling block in those institutions where control is vested in the hands of veterinary scientists, and the animal, not the pasture, is the prime object of study.

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