LEGUMES IN LATIN AMERICAN AGRICULTURE

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The ıelatively few research centres which are active in this field bear no relation to the immense potential of increasing protein production through legumes in these countries. Few isolated groups only have complete research projects on the complexity of factors which interfere in legume agronomy. Inoculation problems which often are considered the only attribute of the so-called "Rhizobiologist" represent one of the minor aspects to be solved with tropical legumes. Most of these species nodulate freely with soil *Rhizobium*, once growth conditions are satisfactory and even when inoculated, often only insignificant parts of the nodules are formed by the inoculated strains. Others, as *Centrosema* and *Stylosanthes* (at least some cultivars) profit from inoculation, although strains isolated from these species are among the best strains on non-specific species as well. The disponibility of a number of strains which produce black nodules and which seem restricted to tropical species, represents a certain compensation for the otherwise most intrinsic *Rhizobium* problems.
Soil fertility studies which deal with legumes grown on symbiotic nitrogen as limiting factor, where major and minor nutrient and toxicities are studied with the whole complex including effects on plant growth, nodule initiation and growth, and nodule efficiency seem to have the most drastic possibilities of yield increases. Legume breeding plant introduction and selection and management, where again nodulation and nitrogen fixation should be considered as one of the major characters to be selected for, represent another potential for yield increases. Native plant and *Rhivobium* genotypes due to the potential natural selection for climatic and edaphic peculiarities should not be overlooked.
In looking for areas suitable for potential protein yield increases, edaphic savannas as those of the Central Highlands of Brazil should be given preference instead of forest areas.

INTRODUCTION

In contrast to most Eastern Countries, the Latin American continent ıs underpopulated and many areas are available, mainly in the central regions, which represent possibilities for potential protein yield increases. More than two. million sq km. of savannas of the Brazilian Central Highlands, for example, are covered up to now with practically useless "cerrado" vegetation, but could be made suitable for mechanized legume cultivation, once the economically justified amounts of phosphorus, lime and minor elements which are the limiting factors, are established (Freitas 1970). This author suggested that such practices could double the Brazilian state budget. A fascinating problem to be solved by legume specialists and soil scientists if one considers that one half of this area alone could produce 30 million tons of soybean protein each year and feed 25 per cent of the actual world population on U.S. standards (100g protein/person/day). These calculations are certainly hypothetical, but they may indicate the potential of the areas which are still unused.

In concentrating efforts for the recuperation of unused land, preference should be given to these types of savannas while the forest reserves, as for example the Amazon region, should be maintained as far as possible, not only for climatic and ecological reasons, but also because the few years of rapidly degrading soil fertility will not compensate for the expenses with cutting the forest. In-between the different types of savanna, the edaphic savannas seem most suitable for agricultural use, while in climatic savannas indispensable irrigation costs do compensate only for highly intensive and sophisticated agriculture, as for example the production of alfalfa hay in irrigated areas of the Brazilian Northeast.

While climatic savannas show caducifolious spiny vegetation with more or less extensive xeromorphism, edaphic savannas are evergreen and show oligonitrophic scleromorphism, as mineral deficiency and not water is the limiting factor of plant growth (Arens 1963). Examples for the first are the "caatingas" in the Northeast of Brazil, while the extensive highlands of Central Brazil and the Venezuelan Chaparradas, denominated "Cerrados", represent the edaphic type (Mors and Rizzini 1966).

Economic importance of savannas as natural pastures might seem small if productivity per hectare is considered, but the immense areas account in Brazil alone for the maintenance of 50 million cattle, which are fed almost exclusively on natural pastures of Cerrado or Caatinga (Ann. IBGE, 1971). In both types of savanna, herbaceous forage legumes are relatively unimportant, while legume shrubs and trees represent a considerable part of the vegetation contributing to the N-economy of these soils which are not generally nitrogen deficient. In the dry season, pods and browse of several shrubs mainly Mimosaceae and Caesalpinaceae represent a major protein supplement to the dry poor quality grass. Most regions under Cerrado receive 6 months of heavy rain, which is enough for the growth period of many crops. Until now only insignificant parts have been taken under cultivation (0.8 per cent) and land use (33 per cent) is on the basis of one animal for 10 ha or more (Marques 1965). In building up more intensive agricultural systems in such areas or in less extensive available regions of the humid tropics or subtropics, the legume *Rhizobium* symbiosis is indispensable as main nitrogen source because mineral nitrogen fertilizers are not only expensive and difficult to obtain, but their application is unthinkable in such large areas with heavy rains where several top dressings would have to be applied to reduce losses through leaching. A large variety of tropical and sub-tropical legumes are available which are referred to in more detail here.

LEGUMES OF MAJOR IMPORTANCE IN LATIN-AMERICAN AGRICULTURE

Grain legumes

As stated above, grain legumes represent the most economic protein source for human nutrition. But even in regions with pronounced protein hunger, it is not easy to introduce unknown grain legumes as general food habits are difficult to overcome. Soybean, the most productive grain legume, which also represents the most complete amino-acid pattern, is consumed in Asia onyl, while many kinds of beans are more important in the African and Latin American diet.

Phaseolus vulgaris is the best known bean species. Black or sometimes brown beans are the every-day food complement on rich and poor tables all over Latin America, and the preference for rice and beans even by well-nourished children before any other food indicates the contents of additional nutrients or minerals which otherwise lack in a common diet in tropical countries. In spite of the high bean consumption (Brazil produces 2.4, India 2.3, China 1.4 and Mexico 1.3 million tons, most of which are consumed locally) (FAO 1970), successful bean growth in all these countries is restricted to sub-tropical areas and elevations. It is a very exigent crop attacked by numerous pests and diseases, with lime requirements as well as high fertilizer needs. In tropical lowlands, beans are grown in backyards mainly, but they are practically everywhere.

The question about inoculation and nitrogen fertilization is the most controversial. *P. vulgaris* is nodulated by a fast growing, species-specific *Rhizobium*, and inoculation should therefore be expected essential, as observed by Whiteway and Nduku (1967) and Sandman (1970) in Central Africa. In Brazil, *P. vulgaris* grown in N-poor but otherwise fertile soils is very often heavily nodulated, although inoculants are seldom used. Due to the short cycle (100 to 110 days), there seems not enough time for the symbiosis to establish itself and fix the necessary amounts of N_2, and mineral nitrogen more often gives significant yield increases. Thirty kg of N/ha at planting or 20 days after, in pot experiments, proportioned increased nitrogen fixation by some strains and reduction by others (Guss and Dobereiner 1970). Brackel and Manil (1965) showed that even under field conditions some host *Rhizobium* combinations can produce twice the amount of green beans than uninoculated plots, and 50 kg N/ha produced 15 per cent less than the best strain.

Significant differences between field-grown cultivars and even lines in nodule weights were shown in our laboratory (Dobereiner 1965) and the better response of poor nodulating cultivars to nitrogen fertilizer confirmed this

(Mesquita 1969 personal comm.). A most puzzling highly significant negative correlation of nodule no. and nodule weight with *P. vulgaris* grain yield was shown in an organic soil where nitrogen was not limiting factor (Pessanha *et al.* 1970). Nodulation was positively correlated with the number of empty pods and the negative nodule effect was attributed to either infestation of the nodules and following parasitation by insects, or to a general resistance mechanism which could be common for pest and disease resistance and resistance against *Rhizobium* infection. A general trend of healthy-looking plants and cultivars being devoid of nodules while cultivars attacked by all kinds of diseases are well nodulated, has been repeatedly observed in bean collections (Costa and Dobereiner, unpublished). A fascinating research problem which, if confirmed, could explain the inoculalation problems with this plant.

In spite of all these difficulties, under optimal conditions as in greenhouse experiments, the bean-Rhizobium symbiosis can fix enough N_2 to meet the plant needs. Amounts of 130 mg N/plant were reached by two plants in 6 weeks (Guss and Dobereiner 1970), while Sandman (1970) reports 280 to 325 mg N/plant in 52 days with five Rhodesian strains, while introduced strains were all less effective.

Phaseolus mungo, P. lunatus and some other species of this genus are important grain legumes in the Amazon region and many other tropical countries. In contrast to *P. vulgaris*, these species are nodulated by the typical non-specific slow-growing *Rhizobium* and the necessity of inoculation has not been shown.

Arachis hypogaea, groundnuts or peanuts represent the second important oil legume which is most important in Africa and Asia. although its origin is probably in the central highlands of Brazil (Duque and Black 1953). Asia produces 8.8 million tons, Africa 4.5 and South America only 1.2 million tons (Jacquinot 1967).

Peanut nodules, in contrast to most other legume nodules originate in the pericycle, their histology being excellently described by Allen and Allen (1940). The peanut symbiosis seems of the unilateral specific type (Doku 1969 ; Sandman 1970), as that of *Centrosema* and certain *Stylosanthes* cultivars (see below). Allen and Allen (1940) observed that every one of 59 cowpea strains was able to produce nodules on peanut in sterilized sand cultures, but 33 strains produced numerous small inefficient nodules, a feature which is not common among other tropical legumes. Its significance under field conditions should be studied as it might explain the controversies about the necessity of peanut inoculation. Effective symbiosis was observed only with 17 strains, 3 of which were from *Arachis*, two from *Desmodium* and two from *Stylosanthes*. *Rhizobium* strains from peanut formed effective symbiosis on all of 13 easy-nodulating species, including *C. pubescens* (Rajagopalan and Sadasivan 1964). Sandman (1970) came to the same conclusion observing in his greenhouse tests (sterilized Leonard jars) that besides 14 strains isolated from peanut, only 6 others out of 22 produced effective symbiosis, two of them from *Desmodium*, one from *Centrosema* and one from *Stylosanthes*. This author observed that field-grown peanuts in Rhodesia are generally effectively nodulated even without inoculation. The same was observed by the author in Brazil.

Glycine max is the most important oil and grain legume in the East, but the USA are by far the largest soybean producers in the world, with 31 million tons produced against 11.5 by China and 3.5 by Brazil (FAO 1971), the two following soybean producing countries. Although soybeans are not a tropical, but rather a subtropical crop, some reference to it seems necessary within this report due to the great importance of this crop in oil and protein production and soil improvement, in the developing countries. It seems the only grain legume which is suitable for mechanized cultivation on large areas and soybean protein yields/ha are the highest obtainable on large-scale basis.

The soybean culture was introduced on larger scale into the South of Brazil about 12 years ago, and is extending with explosive speed onto the Southeast States and very lately into the Central Highlands of Mato Grosso, Goias and Minas Gerais. Table I gives some figures which indicate 50 to 100 per cent increases in soybean production per year and due to the up to now unlimited export market, estimates are for 10,000,000 tons in 1977. Within a few years, soybeans became the second important export product of Brazil (after coffee). Soybeans in all these areas are inoculated and grown without nitrogen fertilizer and inoculation is required by the banking institutions in order to give credits.

TABLE I

Increase in soybean production in several Brazilian States (in tons) (IBGE 1973)

State	Metric/tons produced (approximate data)			
	1960	1970	1972	1973
Rio Grande do Sul	200,000	1,024,000	2,100,000	2,500,000
Paranã	70,000	280,000	500,000	1,800,000
São Paulo	3,000	99,000	210,000	360,000
Minas Gerais	200	1,500	18,000	40,000

There are large differences between soybean cultivars in their performance of the symbiosis (Dobereiner *et al.* 1966; Hardy *et al.* 1971), some cultivars nodulating easily in all soils and with every inoculant, while others usually form only few nodules and are capable of a satisfactory symbiosis only under optimal soil and environment conditions and with specific strains. Unfortunately most highly productive soybean cultivars from the USA are of the latter type, as soybean breeding programmes in this country are more often neglecting completely nodulation ability and selecting their new cultivars in plots heavily fertilized with mineral nitrogen.

Apart from the earlier work initiated by Williams and Lynch (1954) and that of the Beltsville group (Weber *et al.* 1971), which confirms the importance of plant genetic characters in soybean nodulation, to the author's knowledge there is no systematic study on genetics of the soybean symbiosis, a field urgently needed to assure successful soybean breeding for countries where soybeans must be suitable for high yields when grown without mineral N.

Environmental effects on nodulation difficulties were shown by Vincent (1967); it was suggested that easy nodulating soybean cultivars need less calcium for optimal nodulation which is also less inhibited by soil nitrogen (Dobereiner and Arruda 1967). Nodulation difficulties in *G. wenghtii* and *D. uncinatum* were attributed to low calcium extracting capacity (Norris 1967). Recent soybean research is directed to host *Rhizobium* combinations which are less inhibited by additional mineral fertilizer (Hardy *et al.* 1971; Rios 1972, unpublished) and to longer-lasting active nodule tissue.

Soybean *Rhizobium* strains could be divided into two groups, one composed of the large majority of strains which are serologically unrelated and show moderate nodule efficiency and the other of a smaller group of strains, all serologically related to three serotypes, one originated in the USA, one in Australia and one in Japan, with the ability to fix about twice the amount of N_2 per g nodule (Dobereiner *et al.* 1970). This higher efficiency was accompanied by a 20 per cent higher leg-haemoglobin and 100 per cent higher Mo content of the nodules (Pedrosa *et al.* 1970), but was independent of the volume of bacteroid tissue within the nodule.

A laboratory test to differentiate between these two types of strains was based on the growth in liquid medium where the inhibition by 400 ppm asparagine in comparison with 100 ppm was used as differentiation character. The group of very efficient strains was inhibited 75 ± 8.7 per cent while the remaining strains only 11 per cent $\pm$ 8.6 (Pedrosa *et al.* 1970*b*). As nodule initiation and growth seem more sensitive to adverse soil conditions than nitrogen fixation *per se*, *Rhizobium* strains fixing more nitrogen per unit nodule tissue are at advantage in the field compared with less efficient strains ; in the greenhouse, where there is no limit to nodule formation, the two groups of strains might not be distinguished. The group of strains with high nodule efficiency and which was inhibited by DL-asparagine contained most of the strains previously selected as the best field strains in Australia, USA and Brazil.

Vigna sinensis--Cowpeas are much more tolerant to tropical hazards than beans and substitute them therefore to a large extent in the Northeast and North of Brazil and in large parts of Africa, regions where breeding programmes are on the way (Krutman 1968). Nodulation problems do not seem to exist as cowpeas represent the best example for a non-specific, easy nodulating species. It is everywhere found abundantly nodulated and there seems to be sufficient nitrogen fixation to meet the plant needs (Jacquinot 1967). Day length, light intensity and root temperature interfere in cowpea nodulation (Tewary 1966; Dart and Mercer 1965; Doku 1970) and inefficient nodules were found with 8h days. In the field or in pots, however, non-specific tropical legumes grown under normal temperature and light conditions of the tropics only exceptionally were found by the author to produce inefficient, white nodules. Also the climatic effects on nodule distribution reported by Dart and Mercer (1965) and Tewary (1966) are of little practical importance as freely nodulating but not inoculated plants always produce nodules scattered over the whole root system. The much distributed thought that only nodules on primary roots are efficient is probably originally derived from the typical inefficient small nodules scattered in large numbers over the whole system observed on clovers. This type of nodules is not common in tropical legumes and the only advantage of nodules situated on primary roots seems the early infection and initiation of fixation, which might be enhanced by artificial inoculation. Its practical advantages, however, have to be proved yet. Another reason for nodules situated often as far away on the primary roots as 10 to 20cm is that in the hot season, on many legumes, nodules are formed only deeper in the soil, where temperature extremes are less severe.

Grain yields of cowpeas are generally reported as 560 to 1000 kg and can reach 1200 kg to 2000 kg in Brazil (Krutman 1968) and Mexico (Schmidt and Marcus 1943). Few field data on nitrogen fixation are available, but the amount of nitrogen removed is considerable as pods and grains contain 56 to 84 per cent of the total plant nitrogen (Jacquinot 1966). Wetselaar (1968) reports nitrogen fixation of 83 kg/ha in a three-year average in the short monsoon season, but this amount was not enough to compensate for nitrogen removal in the harvest.

Cajanus cajan, the pigeon pea, is an important human and animal food in Asia, Africa and Latin America. In the Dominican Republic it is cultivated for grain production (Guzman, pers. comm), while in Brazil it is rather grown in backyards of small farmers who eat the green grains as peas. *Cajanus cajan* was recommended by Schaafhausen (1967) as valuable forage plant, who planted it in 5 m distant rows, parallel to the hill slopes, when it solved also erosion and wind problems.

Pigeon pea has also not been reported to require inoculation. It nodulated freely. Oke (1967) compared nitrogen fixation of pigeon pea with that of *Centrosema* and *Stylosanthes* and found values of 100 mg N/plant fixed in three months when *Centrosema* fixed 72 mg and *Stylosanthes* 32 mg. Young plants were more active than older ones; 200 mg N/day/g nodules being observed on six-week-old plants while the maximal N_2 fixation rates were obtained by *Stylosanthes* after 3 months only (153mg N/day/g nodules). Eighty to hundred per cent of the fixed nitrogen was transferred to the plant. Field balance sheets indicate 90 to 150 kg N/ha in tropical Australia (Date 1971; Wetselaar *et. al.* 1971).

Forage legumes

Until not long ago, the opinion prevailed that tropical legumes were a necessary but poor substitute for medics and clovers, but much work has been done recently, mainly in Queensland, which proved a number of tropical forage legumes equivalent or even better. In selecting tropical legumes for forage purposes, a number of characters are important, high forage yield in the dry season, medium palatability besides tolerance to temperature extremes or rapid recuperation thereafter, late flowering and high nutritive value being cited by Williams (1964). A high degree of palatability is not as important in a legume as in a grass. Medium degree of palatability can be of advantage in assisting its persistence and its ability to build up nitrogen in the soil (Hutton 1964).

Not all tropical forage legumes nodulate promiscuously with common soil *Rhizobium*, and special inoculation problems will be cited for these species below. Most of them, however, cross inoculate as freely as cowpea. These species except under extreme conditions are always abundantly and effectively nodulated. Inoculation is not only unnecessary; it does also not have much sense. Using strains which produce black nodules, Cloonan and Vincent (1967), Dobereiner and Coser (1970) and Date (1971) showed that even under optimal conditions and with high inoculum on such species, only a small fraction of the nodules are formed by the inoculated strains.

Although the *Rhizobium* specialist tends to favour work with problem species, because there is not much he can do about promiscuous species, we think it one of the most important advantages for a forage crop that there is no need to bother about inoculation, and that the necessary nitrogen for plant growth under most soil conditions will be available through the symbiosis. Hutton (1964) calls attention to the breeding possibilities for species like siratro, for stoloniferous or rhizomatous rooting habit which results in the continual replacement of aging roots by young vigorous ones which nodulate freely. Forage legumes within the promiscuously nodulating group are the following :

Phaseolus atropurpureus cult. *siratro*, an artificially bred cultivar selected for transgressive segregates with stoloniforous character (Hutton 1964). At the moment it seems to be the most promising forage legume, specially for consorciation and in warm areas (Bermudez *et al.* 1961; Rocha *et al.* 1970). In a number of studies this legume compared favorably in forage production when consorciated with grasses (Table II). One of the limitations of this species is the difficulty of obtaining commercially produced seeds although this problem has been solved in Australia (Redrup 1965). In Brazil *P. atropurpureus* seeds are difficult to obtain besides being very expensive. In cooler regions *Oidium* attack and leaf drop represent a limit to forage production. Grazing of this species reduced nodule weights but not numbers (Whiteman and Lulham 1970), indicating shedding and a fast regeneration of the nodules, a mechanism which might be responsible for the transferrence of nitrogen from the legume to the grass.

TABLE II

Total nitrogen assimilated in forage in 207 days (August till March) in poor yellow latosol on Hill lane. (Mean of 4 replicates). (De Polli *et al.* 1972)

Forage Composition	Kg N/ha in forage
Pennisetum purpureum	38.8
P. purpureum with 2 times 50 kg mineral N	62.0
P. purpureum with *siratro*	82.7
P. purpureum with *pubescens*	53.2
P. purpureum with *P. javanica*	58.0
P. purpureum with *G. wenghtii*	58.5
P, purpureum with *S. guyanensis*	74.0

When compared with *Centrosema*, *Stylosanthes* and *Glycine javanica*, *P. atropurpureus* reached the highest nitrogen fixation yields, reaching 85 per cent of its maximal protein assimilation capacity with mineral N. This value was 54, 48 and 32 per cent respectively for the three other legumes (Dobereiner 1970). N^{15} studies showed that apart from N absorbtion during the first three weeks only 2 to 4 per cent of the plant nitrogen was absorbed from the soil (Henzel *et al.* 1968). Compared with the same legumes, *P. atropurpureus* was also the less sensitive to minor element deficiencies (Franca and Carvalho 1970). Besides treatment effects, the interaction species treatments was highly significant.

Pueraria phaseoloides, tropical kudzu, is recommended as the most promising forage legume in Surinam (Dirven 1965) where the annual mean temperature is 27.1°C and rainfall varies from 1680 to 2420 mm, in Porto Rico (Vicente-Chandler *et al.* 1953), and also in the Brazilian Amazon region. Kudzu in these regions is grown in mixed awards with grasses and as ground cover of citrus or rubber plantations (Dirven 1965). Chemical composition shows high protein, potassium, calcium and crude fiber content, but low sodium and sulphur values. In mixed swards *Digitaria decumbens*, kudzu yielded 1843 kg dry fodder, 61 per cent of which was constituted by the legume (Riveros 1960). The protein content of the pangola grass was not increased. Vicente-Chandler *et al.* (1953), Vicente-Chandler and Abruno (1966) observed good establishment of kudzu on steep hillsides (up to 50 per cent declivel) in molassis grass *Melinis minutiflorts* pastures where bean yields of 1100 kg/ha/year (mean of 10 years) were obtained without concentrates. This is more than 4 times the productivity of native grass pastures. Total protein yields were 2,500 kg/ha in two years, which was equivalent to 200 kg N/ha/year from which one half was in the grass and one half in the legume. Protein content in the grass increased linearly with the percentage of kudzu in the mixture (from 5 to 8 per cent crude protein).

TABLE III

Limiting factors for legume growth and nitrogen fixation in a cerrado soil classified as red latosol (Mean of 3 pots) (France and Carvalho 1970)

	G. javanica (mg/pot)		*C. pubescens* (mg/pot)		*P. atropurpureus* (mg/pot)	
	Nodules	Plant N	Nodules	Plant N	Nodules	Plant N
Blank	0.4	16	1.3	23	10.9	25
minus P	1.5	43	5.3	55	4.6	34
minus K	85.8	134	106.8	117	264.3	157
minus S	183.2	136	115.2	96	229.6	126
minus Zn, Cu, B, Mo, Fe	0.7	20	2.8	62	94.1	104
minus lime (Ca, Mg)	179.5	43	277.7	61	235.6	69
Complete	232.2	127	78.7	103	223.9	128
Complete±N	1.7	238	8.0	122	15.9	189

Calopogonium mucunoides is an annual legume which very easily propagates itself by seeds, and in Rio de Janeiro State is found everywhere on roadsides and may dominate completely the sward. Under these circumstances it is considered a pest. Other authors consider it a valuable forage legume (Motta 1952). In consorciation with pangola grass, it was the most productive with 2,253 kg dry fodder/ha, where 85 per cent consisted of the legume. After an adaptation period it became the most palatable legume among 10 others (Stihnmeyer, pers. comm.)

Galactia striata, a native Phaseoloideae which has been selected very recently in Sao Paulo (Rocha *et al.* 1970) and which according to this author presents the following advantages when compared with siratro:

(i) Larger seeds which are easier to harvest and germinate better.

(ii) Drought resistance resembles that of *Stylosanthes* and there is growth several months after the rains stopped. *Galactia* remains green all winter and starts growing in August, before the first rains.

(iii) Nodulation is as abundant and non-specific as that of siratro and palatability is superior.

(iv) Large-scale productivity will still have to be proved.

A second group of tropical forage legumes possess a strain specificity of varying degrees. If not inoculated, they will select from soil *Rhizobium* suitable strains and establish in a slow patchy fashion which, in the second year, may lead to successful establishment (Norris 1967). In most of these species inoculation gives an advantage in uniformity and speed of establishment. In other species soil factors are decisive for good nodulation, and inoculation does not help much. Legumes of this group are the following:

Glycine wenghtii is a vigorous prostrate legume which grows with a number of grasses when conditions are suitable. In Brazil, by far the largest area of sown legume pastures is covered with this species (Rocha *et al.* 1970). In this country initially very optimistic estimates based mainly on commercial seed company advertising were later contradicted upon experimental evidence of the high requirements of this plant on soil fertility and lime. Nodules were very seldom found under field conditions, and satisfactory development was obtained only with heavy liming and phosphorus applications. Souto and Dobereiner (1968) came to the conclusion that soil acidity, manganese toxicity and phos phorus deficiency besides excessive soil temperatures are harmful to nodulation, while under optimal greenhouse conditions this legume nodulated freely with most promiscuous strains. Similar to soybeans, there are large differences between cultivars which, to a certain extent only, can be compensated by strain selection, Tetraploid cultivars nodulate earlier and more profusely (Diatloff and Ferguson 1970), and Nicholas (1971) observed better and poorer nodulation in lines obtained from crosses, so there might be a possibility of genetic improvement. On the other hand, the nodule attack by larvae of *Rivellia* sp. (Diatloff 1965) and the late nodule initiation (Diatloff and Ferguson 1970) and the low percentage of bacteroid tissue in *G. wenghtii* nodules are further restrictions.

Nitrogen contribution under optimal greenhouse conditions is comparable with other legumes (about 150 mg/pot with 1 kg) (Dobereiner and Coser, unpublished), but no data are available from the field.

Stylosanthes guyanensis has its origin in South America where it occurs spontaneously in many areas, even in the extremely poor cerrado soils, there especially after heavy grazing. In these areas it is the most important forage legume for sown pastures, as well as for oversowing natural pastures. It was introduced in Australia, Nigeria and many other tropical countries with success (Haggar 1971).

Besides excellent forage quality and high palatability, *S. guyanensis* is specially valuable in the dry season in raising the quality of natural grassland, growing up to four months after the last rains (Haggar 1971).

The inoculation problem of *S. guyanensis* seems still controversial. Norris (1964) states that this plant is never known to fail to nodulate in the field, but in between 11 *Rhizobium* isolates of such plants only two were highly effective. A Brazilian variety (IRI 1022) grown in nitrogen-free sand and culture fixed 29, 16, 12, 3, 2 and 1 mg N/pot respectively with five soil series used as inoculant, the difference between soils being highly significant. (Souto, Coser and Dobereiner 1970). In the same experiment the strain CB756, the strain recommended in Australia for the inoculation of *S. guyanensis*, did not form one nodule. In between 21 other strains from 7 promiscuous legumes only two formed nodules on this variety, one from *C. pubescens* and one from *C. mucunoides*. Two other cultivars were less specific. Sandmann (1970) also came to the conclusion that *S. guyanensis* needs specific strains and with a "non-specific" cultivar observed effective nodulation with 9 strains (3 from *S. guyanensis,* 4 from *Desmodium* spp.), inefficient nodulation with 8 strains and no nodules with 22 strains, all from promiscuous legumes. Recent strain recommendations for fine stem stylo in Australia are also specific (Date, pers. comm.).

This apparent discrepancy of field and greenhouse data either indicates that *S. guyanensis* nodulation in the field is very often abundant but inefficient, or that Leonard jar greenhouse tests for this plant, which is extremely sensitive to high *p*H (above 6) which is normally used in Leonard jar tests (even by Norris) do not mean much. Due to results of a recent pot experiment with soil, we are inclined to favour the latter hypothesis.

It is interesting to observe, however, that in Sandmann's expriments as well as in ours, most non-homologous strains which nodulate *S. guyanensis* are either from *Desmodium* or from *Centrosema pubescens.* In a cross inoculation test with *C. pubescens* furthermore (Coser, unpublished), in-between 21 non-homologous strains 5 were able to nodulate, 3 of which were strains from *S. guyanensis.* On the other hand, among the strains nodulating these problem species, which in no case took advantage when inoculated with homologous strains effectively, are the best strains for promiscuous species, It might therefore be that the apparent specificity is rather a certain difficulty to nodulate and only very infective and efficient strains are able to produce an effective symbiosis on the problem species. Bowen and Kennedy (1961) found one very effective strain which nodulated well even sparsely nodulating lines. This would indicate that instead of starting to select strains from the homologous species for which we have no supporting data, strain selection programs should rather start with strains which nodulate *Centrosema. Stylosanthes* and *Desmodium.*

Nitrogen fixation of *S. guyanensis* under field conditions is superior to most tropical forage legumes except siratro (Table II). Haggar (1971) also showed the great superiority of this legume in Nigeria when compared with *Centrosema* and *Desmodium.* From his data by subtracting the protein yield of pure grass from that of Stylo, nitrogen fixation of 98 kg/ha was reached in the third year. In comparing the protein yield of *S. guyanensis*/grass (*Cloris guayana*) mixture with pure grass, 820 kg of mineral N were necessary to equal protein yields of the latter. Applications of nitrogen to the legume-grass mixture yielded only 0.28 kg N/acre per N applied, while the pure grass yielded 0.48 kg N/kg N applied. Nwosu (1960) also in Nigeria reported the production of 3,980 kg/ha of hay in 6 months with a crude protein content of 17.57 per cent (which corresponds to a nitrogen assimilation of 112 kg/ha. Nitrogen gains of 90 kg/ha/year are also given by Wetselaar *et al.* (1971). *S. guyanensis* meal prepared from hay compared economically with groundnut cake, both being 45 per cent cheaper than palm kernel meal (digestible crude protein basis).

Centrosema pubescens is also native in South America. Its use is limited to humid tropics and subtropics due to its sensitivity to low temperatures. It was one of the first forage legumes propagated in Brazil, but it is now losing interest in comparison with *siratro* and *S. guyanensis*.

The symbiosis of *Centrosema* is moderately specific (Norris 1967), nodulation with heterologous strains being so unfrequent that one could admit that strains derived from other species nodulating *Centrosema* might originally be derived from this species, as most *Centrosema* strains are very effective on promiscous species; as mentioned before, *Centrosema* is one of the few tropical legumes for which host genetics information is available (Bowen and Kennedy 1961; Serpa and Cunha Filho 1970). Both authors observed that commercial seed contained stable sparsely and nodulating lines. Lower nodule numbers could be compensated, to a certain extent only, by larger nodules and some strains were able to produce enough nodules for satisfactory nitrogen fixation even on sparsely nodulated lines. But, as said above, host specificity in these species seems rather a difficulty to nodulate which is overcome only by few exceptionally infective strains.

Forage yields of *D. pubescens* are more often lower than those of siratro or stylo (Table II), but there are reports of exceptionally high nitrogen yields: Waston (1957) found 232 kg/ha in Malaya fixed in 5 months and Moore (1962) reported as much as 530 kg/ha/yr in West Africa. *Centrosema* also was more effective than *S. guyanensis* in increasing nitrogen content of grasses (Moore 1962) as *Desmodium* (Whitney *et al.* 1967), possibly due to the easier shedding of nodules which are mostly situated loosely on secondary roots. In controlled experiments in polyethylene linings, but in the open air, Whitney *et al.* (1967 measured 264 kg N/ha fixed by *C. pubescens*, but only when grown in pure stand.

Desmodium spp.—There are a number of species of this genus which are being used as forage legumes. *D. barbatum* is common in sown and natural pastures in Central and part of South America. It was recommended by Semple (1964) for soils of very low fertility and is resistant to flooding and close grazing. *D. intortum, D. sanwicense* and *D. uncinatum* are the most common species used in Australia (Williams 1964).

Following Diatloff (1968) and Norris (1967) at least *D. uncinatum* and *D. intortum* are moderately specific and a special strain is recommended in Australia for these species. This plant, as *G. wenghtii*, has a comparably low calcium extracting capacity (Andrew and Norris 1961) and nodulation difficulties might be due to lack of calcium, specially in *D. uncinatum* (Norris 1971). Nodulation of three *Desmodium* species was not related to flowering, nodule number varied between species, but the regression of total plant N with nodule weight was constant with all three varieties, in young plants (Whiteman and Lullham 1970).

Nitrogen gains by *Desmodium* species might be considerable. Whitney *et al.* (1967), using polyethylene lined outdoor plots, came to values of 320 to 360 kg N/ha/year fixed by *D. intortum*, while *D. canum* fixed only 42 to 121 kg. Richard and Bevege (967) measured nitrogen increases as 5-year average in pine forests with legume ground cover on lateritic podsolic soil. They obtained values of 110 kg/ha for *D. uncinatum*, where *P. atropurpureus* fixed 90 and Lotononis 44 kg/ha/year. Increasing phosphorus levels increased nitrogen accumulation in soil under *D. uncinatum* from 70 to 124 kg/ha/yr in Queensland (Henzell *et al.* 1968).

Green manure

The economic value of green manure as a general practice under tropical conditions still will have to be proved (Williams 1967; Verdade 1971) and late-soils with very low base exchange capacity seem more promising if any for such practices (Joffe 1955).

Green manure problems in tropical soils seem inverse to those in temperate soils, that is decomposition is too fast and there is very little residual value beyond one year or often much less (Joffe 1955). This author attributes frequent beneficial effects of green manure in lateritic soils to the liberation of minerals. Agricultural practices should therefore envisage short-term effects as improved water infiltration and water-holding capacity, erosion control, and plant disease and pest control, besides the most important character of green manure legumes, the enrichment of the soil with gradually liberating nitrogen sources. Cover crops in orchards or coffee plantations, even with legumes, give more frequently negative results which were attributed to competition for water. More promising results were obtained with flooded rice, as the decomposition of the green manure (*Vicia*) in the rice paddy resulted in highly efficient recovery by the growing rice crop of the nitrogen mineralized from the green manure (Williams 1967). Similar results are obtained with a flood-tolerant photoperiod independent soybean cultivar (Santa Maria) which is planted in the winter in rice paddies in the Paraiba valley in Brazil. The use of *Cannavalia ensiformis*, *Crotalria juncea* and *Stizolobium deeringianum* as green manure with maize as subsequent crop gave yield-increases corresponding to 60 kg N/ha, not competing economically with higher mineral fertilizer levels (Ruiz and Laird 1961). All tropical legumes used as green manure nodulate promiscuously with soil *Rhizobium* and inoculation is not necessary. Exceptions are given by Mes *et al.* (1957) in South Africa. There is a large number of species which occasionally might be used as green manure, reference being made here to the most important ones:

Crotalaria—A number of species of *Crotalaria* have been used, *C. juncea* being the most common one. Mes (1957) recommends *C. intermedia* as the most suitable, due to higher yields and nitrogen contents. *C. recta*, a very tall species with an overall lower nitrogen content, fixed as much N_2 (up to 7 g/plant). Catani and Gargantini (1954) estimated N_2-fixation of *Crotalaria juncea* at 0.74 g N/pot with 6 kg/3 months, and recommended *C. juncea* as green manure for the recuperation of acid, very poor, sugarcane soils.

Green manuring of maize with *C. juncea*, *Canavalia ensiformis* and *Stizolobium deeringianum* corresponded to 60 kg N/ha, not competing economically with higher mineral fertilizer levels (Ruiz and Laird 1961).

Very promising seems the use of green manure for field beans, which in Brazil are usually planted in February, at the end of the summer and the preceding months give ample time for the development of another short term crop. Substantial yield increases of beans have been attributed to better water holding capacity, better aeration and the availability of a slow flowing nitrogen source and results of numerous field experiments indicate *Crotalaria juncea* incorporated into the soil just before sowing as the most promising (Table IV).

TABLE IV

Effect of green manure incorporated immediately before planting of field beans, in São Paulo State (mean of 3 field experiments) (Miyasaka *et al.* 1965)

Green manure	Amount of plant material incorporated, kg/ha	*P. vulgaris* grain yield, kg/ha
Crotalaria juncea	57.797	800
Cajanus cajan	25.026	637
Dolichos lablab	31.656	591
Tephrosia candida	13.884	609
Sorghum vulgare	56.025	416
None	-	418
L.s.d. (Duncan)		165

The lack of any effect of the incorporation of large amounts of sorghum indicate nitrogen effects. This was confirmed by yield increases of 41 per cent in an average, of 8 other field experiments by *Crotalaria* green manuring, which were reduced to 11 per cent when nitrogen fertilizer was applied (Mascarenhas *et al* 1967). In three field experiments, also on cerrado soil, rice after *C. juncea* and field beans yielded 21 to 38% more than rice after rice (Santos et al. 1972). All these results show short-term effects where soil improvement cannot yet be important.

Kiel (1959) proposed another interesting possibility to increase green manure yields and quality by consorciating erect legumes as *Crotalaria* or *Cajanus* with creepers as *Dolichos lablab*, *Stizolobium* or *Vigna*.

Canavalia ensiformis — This plant, as *Crotalaria*, unites high green matter production with the advantages of an erect non-creeping growth habit. In Mexico, five-year experiments involving ten maize crops with four legumes intercropped showed *C. ensiformis* as the most promising, although the yield increases of the succeeding maize crop were partially offset by the depression of the associated maize crop (Williams 1967). Nitrogen fixation was measured in pot experiments by Gargantini and Wutke (1959) who interpolated to 48.5 kg N/ha fixed in two months.

The interesting characteristic of *C. ensiformis* of inhibiting the growth of *Cyperus rotundus*, a weed (Magalhes and Franco 1962) might give additional reasons of using this species as green manure for perennial crops. The same authors (1962 *b*) showed that the inhibition of *C. rotundus* was due to the presence of root nodules, fresh or boiled nodule extract reducing growth to one fourth or less. Extracts of roots had no effect.

Stizolobium deeringianum produces much green mass which is easily incorporated due to its herbaceous consistency, but decomposition in soil is extremely fast (Menezes and Araujo 1967). The creeping habit is another disadvantage when planted as soil cover in orchards. Yield increases of maize in latosols of the cerrado region, in the 3rd and 5th year, when in rotation with *S. deeringianum*, were reported by Menezes and Araujo 1961. Data for nitrogen fixation are sparse, 227 mg N/plant/2 months being given by Mes (1957) and 150 to 545 mg/plant/68 days by Sandman (1970), both in pots.

Forest and shade legumes

In tropical South America, besides grain and forage legumes, forest and shade legumes are of considerable importance. Among the most important wood species in natural forests many are legumes : *Poltogyne nitens, Centrolobium tomentosum* and the most important wood species of the lower Amazon region *Vouacapoua americana* are examples. *Mimosa caesalpiniaefolia* produces fast-growing but heavy hardwood for fences and posts and is used in the dry season as protein-rich forage supplement for cattle and goats in the Brazilian Northeast (Caatinga). Acacia species are a main component in the reforestation in the subtropical South. *Acacia*, as well as *Mimosa* spp., present specific *Rhizobium* requirements as most Mimosoideae form a specific cross inoculation group (Campelo and Dobereiner, 1969), and inoculation is essential when the plants are being transplanted into new land. Most *Rhizobium* strains from Mimosoideae are fast-growing but do not produce acid and are therefore easy to isolate and identify. Inoculation of seedbeds with selected strains leads to abundantly nodulated seedlings which in the field compete much more successfully with the natural vegetation (Fig. 1) than seedlings from manure seedbeds which are generally not nodulated. The advantage of reforestation with such species against Eucalyptus, from the point of soil conservation, is unquestionable, unfortunately reforestation in Brazil is mostly done for economic reasons in which case it is more difficult to compete with Eucalyptus or pines.

An agricultural practice restricted to the tropics is the use of shade trees for cocoa, coffee and tea. There is an extensive literature on the subject, but very little is known about the nitrogen contribution of these shade trees (Havord 1959). A number of legume trees have been used for shade : *Inga* spp. are commonly used for coffee shading. *Erythrina glauca* is one of the most recommended shade species for cocoa in Bahia. These trees frequently were found with countless nodules on the superficial roots all over the plantation. Zevallos (1966) reported significant cocoa yield increases when he compared cocoa trees near the Erythrinas with others farther away. He attributed this difference to a higher base saturation and a higher humus and nitrogen content of the soil near the Erythrinas. The difference in nitrogen content in mean of five samples was 0.032% of N corresponding for a 15cm layer to 480 kg N/ha. *Erythrina poeppegiana* shaded cocoa trees in Costa Rica constantly outyielded those under three non-leguminous shade trees and little or no response to nitrogenous fertilizer was observed with the *Erythrina* shaded cocoa, while unshaded or shaded with non-legumes cocoa responded consistently (Havord 1959).

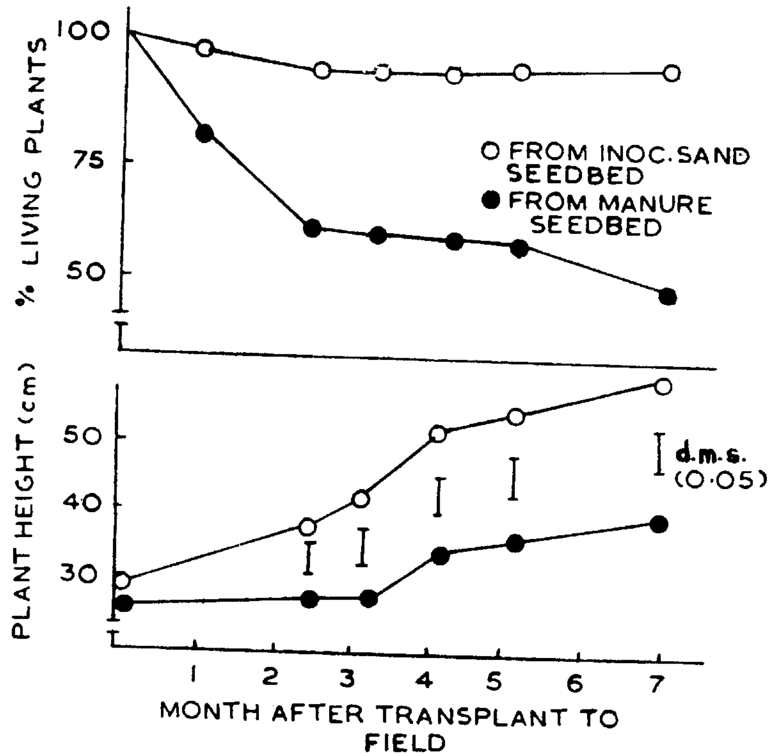

Fig. 1. Survival and growth of seedlings of *Mimosa caesalpiniaefolia* in the field. Seedlings from inoculated seedbed were heavily nodulated at transplant, those from manure seedbed had only few nodules. (Mean of 4 replicate plots, 16 plants each). (*Dobereiner 1966*).

Rhizobium Research in Latin America

The potential of protein yield increases in these areas cited in the introduction calls for intense research activity in plant breeding, soil fertility and

Rhizobium problems. Although some progress has been made, very much remains to be done and should be done urgently, as the rapid expansion of some cultures as that of soybeans into large areas of up to now useless cerrado soils is faster than the few research centres can cope with.

It is impossible in these pages to give a complete coverage of *Rhizobium* research under way in Latin America, and the reader is referred to the Annals of the IV and V Latin American Meetings on *Rhizobium*, where most of the more recent papers are summarized, and to Latin American literature. A brief outline of the more important research lines and results is given in the following lines, as far as not mentioned under the individual crops before :

Inoculation problems which often are considered the only attributes of the so-called "rhizobiologist" represent only one of the aspects to be solved. Strain selection programmes are under way in Uruguay, Argentina, Chile and Porto Alegre (Southern Brazil) for clovers, alfalfa, and some other temperate species ; for soybeans, in Argentina, Porto Alegre, Curitiba, Campinas and Rio de Janeiro ; and for tropical forage legumes in Curitiba, Campinas and Rio de Janeiro. In all these programmes soil factors in relation to survival and competition with native *Rhizobium* are considered. The importance of these studies for subterranean clover for example, is demonstrated in Table V, where it becomes apparent that different strains responded differently to liming and how important liming is to guarantee survival of clover Rhizobium.

TABLE V

Effect of liming on survival of different Rhizobium strains in soil planted with subterranean clover (Means of 3 replicates, nodule dry weights mg/pot of plants inoculated at planting and of replants one year later, without inoculation) (Kornelius *et al. 1972*).

Inoculant	Year	Lime in t/ha		
		0	1.2	2.4
Check	1970	0.0	0.0	0.0
No	1971	0.0	0.0	0.0
E 222	1970	114.1	99.7	104.7
No	1971	20.0	141.8	85.3
E 235	1970	114.1	120.5	146.4
No	1970	20.4	84.0	91.4
E 239	1970	92.5	98.1	99.5
No	1971	0.0	87.6	115.1
E 165	1970	113.0	109.8	123.1
No	1971	0.0	198.5	119.3

Strain selection for promiscuous tropical legumes is complicated by the presence of native strains which often are less effective but sometimes better than the best inoculated strain (Lopes *et al.* 1970, Dobereiner 1970). The fact that specially *Stylosanthes* nodulates constantly more effectively with certain soils used as inoculant than with pure *Rhizobium* strains indicates that selection, in sterile nsutral Leonard jars is insufficient for this acid-tolerant species.

A recompensation for the intrinsic *Rhizobium* problems with tropical species is the disponsibility of strains which produce black nodules (Dobereiner 1970), which permit identification of the inoculated strain upon simple observation. Sandman (person. comm.) reported several additional "black" strains one of which from *Desmodium* was shown in our laboratory to form black nodules on soybean. Whether these nodules are efficient has not yet been shown, inefficient black nodules on *Phaseolus vulgaris* have also been shown (Campelo and Dobereiner 1969). An example for the utility of "black strains" is shown on Table 6, where the effect of seed pelleting with F.T.E. (fritted trace elements) on survival of inoculated strains in an acid red yellow podzolic hill soil is shown.

Serological testing of strain competition under field conditions confirmed large differences between soybean cultivars (Araujo *et al.* 1970). Based on numerous field experiments, it was concluded that locally-selected or locally-reisolated and retested strains are always more effective than imported inoculants. It seems therefore essential for introducing a new legume crop in a region to develop inoculants for the cultivars and soils to be used, specially if specific legumes are concerned. Soybeans are outstanding in this respect as the extensive breeding work in the U.S. lead to cultivar specific highly sophisticated *Rhizobium* requirements. Very recently studies on non-nodulating factors appearing in several new soybean lines are under way in our laboratory.

TABLE VI

Effect of fritted trace elements (F.T.E.) on nodulation and ntirogen fixation of two Forage Legumes in red yellow Podsolic Soil (De-Polli and Dobereiner, unpublished).

	Black nodules (mg/pot)*		Total N in plants (mg/pot)	
	C. pubescens	*P. atropurpureus*	*C. pubescens*	*P. atropurpureus*
No trace elements	4.3	50.2	365	487
F.T.E. in soil	39.8	56.5	741	765
F.T.E. as pellet	0.5	86.0	633	872
F.T.E. as double pellet with lime	11.8	92.8	788	966
F.T.E. as double pellet with rockphosphate	3.8	95.0	697	877

* Black nodules were formed from the inoculated strain, they represented only 0.3% in mean in *C. pubescens* and 28% in mean in *P. atropurpureus*, in relation to the total nodule weight.

The most spectacular yield increases of grain and forage legumes are to be expected by research projects which envisage economically justified lime and fertilizer use on legumes grown with the *Rhizobium* symbiosis as sole nitrogen source. The study of different effects of major and minor nutrients and toxicities on the different components of the *Rhizobium*-legume association will explain individual responses and lead faster to results with wide-range application.

Highly lixiviated and mineral-deficient latosols predominate in tropical and subtropical regions, and are responsible for the low productivity of these areas. For the economic recuperation of these soils, legumes are indispensable, at least as part of crop sequences as they do not require the most expensive of the fertilizers, nitrogen, which in these areas is also lixiviated extremely fast and used by the plant by 25 to 40 per cent maximally, even if several top dressings are applied during the growth cycle. The relatively high initial investments of phosphorus, minor elements and lime necessary in most of these soils are compensated by the very low costs of such land (one ha of typical cerrado land in Central Brazil costs 10.00 to 30.00 US $ while the better soils in this area are sold for 150.00 to 200.00 US $). Cleaning, liming and application of 0.8 t of rock phosphate, labor included, is estimated in US $ 164.00 from which 24.00 can be subtracted for selling coal from the wood (Mauthe 1967). Soybean yields in such soils reached a return of US $ 200.00/ha, additional superphosphate discounted (Lobato *et al.* 1967). This means that acquisition and cleaning such soils as well as initial fertilizer investments can be payed for with one soybean crop.

Liming and phosphorus are essential in newly-claimed cerrado land and in 4 out of 5 field experiments yield increases paid for more than 3 times the fertilizer investments (Santos *et al.* 1972 ; Lobato *et al.* (1967). Successive dry bean (*Phaseolus vulgaris*) yield increases from 300 to 3000 kg/ha, or five times the Brazilian average, were reported after 4 years of lime (4 t), phosphorus (160 kg P_2O_5) and green manuring with *Crotalaria* (Guazzoli and Pedreira, person. commun.). These data indicate the potentiality of the vast areas of cerrado soils (more than 2 million sq. km), which represent excellent physical conditions and are suited for mechanised agriculture as few others. Less spectacular, but still promising, is the introduction of legumes into hilly pastures where phosphorus and minor element fertilizers are given in plant holes or rows to give the legumes a start in competition with the natural grass pastures. Trace element deficiences are common on such hills (Table VI).

Research programmes for the introduction of legumes, or the suitable species are known, should start with exploratory experiments to determine limiting factors as the one demonstrated in Table III, which shows the extreme mineral poverty of a Red latosol, typical for large areas of the cerrado region. Once the limiting factors are known, field experiments are carried out where economic levels of the major factors, generally phosphorus and lime, are studied in factorial experiments, all other limiting minor or major elements being furnished. An example of such an experiment is given in Fig. 2. Simul-

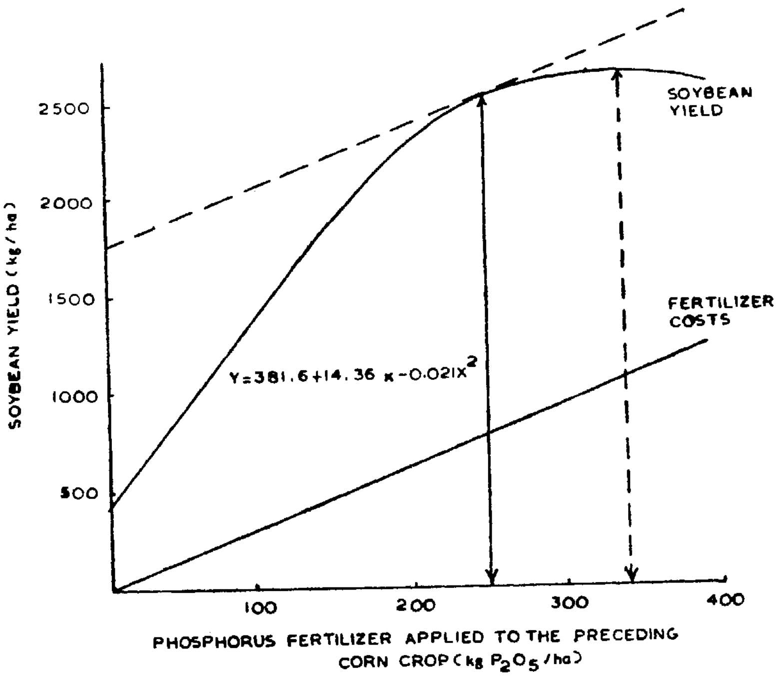

Fig. 2. Effect of phosphorus fertilizer on soybean yield in cerrado soil (*Lobato et al. 1967*).

taneously, pot experiments for more detailed study of interactions of lime with individual minor elements are carried out as for example the intrinsic problem of negative effects of liming on *Stylosanthes* yields (Freitas and Pratt 1969 ; Vargas and Dobereiner, unpublished) which has been attributed to low minor element extracting capacity of this plant, mainly manganese and boron, and which become limiting at *p*H above 5.5.

The question of liming tropical legumes has been extensively discussed and represents a subject of most controversial hypotheses. Unfortunately the number of experiments in favor of each of the different hypotheses is insufficient to give clearcut evidence for either. Norris (1956, 1964, 1967) introduced the concept that tropical legumes do not need lime as these species have a higher ability to extract calcium (Andrew and Norris 1961) and acid-tolerant *Rhizobium* strains. Liming can even be harmful by accelerating soil degradation (Norris 1967) or by reducing the availability of certain minor elements as shown above with *Stylosanthes*. The indiscriminate use of lime in any acid soil to bring it to near neutrality is also often uneconomic, and certainly should be condemned. But there are immense areas as those of the cerrado region where aluminium toxicity even at relatively low exchangeable Al^{+++} is prominent (Goodland 1971) due to very low base exchange capacity and a Ca^{++}

Mg^{++} Al^{+++} ratio below 5 or even 2. In these soils liming is indispensable for legume growth, as shown on Table VII. Magnesium in this experiment was given as basic dressing and it can be seen that minor element application only partially compensated for liming, and even *Stylosanthes* yields were maximised only by liming. The question of liming tropical legumes seems therefore far from being solved, and much basic and also applied research is necessary to assess lime requirements for these species, in each specific case, while generalization in any direction seems inadequate.

TABLE VII

Effect of lime (4g $CaCO_3$ p.a./kg soil) and minor elements on dry matter production (g/3 pots) of tropical forage legumes in virgin cerrado soils (p*H 4.3*) (Aidar 1972, unpublished)

	Glycine wenghtii	*Stylosanthes gracilis*	*Phaseolus atropurpureus*
Dark red Latosol			
No lime, no minor	3.11	6.86	7.89
No lime, minor el.	4.65	11.86	9.93
Lime, no Minor el.	9.18	15.43	20.07
Lime and minor el.	12.26	18.28	20.35
Red yellow Latosol			
No Time, no minor el.	2.97	7.49	6.42
No lime, minor el.	4,34	12.04	11.16
Time, no minor el.	6.53	15.48	15.90
Time and minor el.	8.27	16.38	16.17

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