Perspectives on the adaptation of pasture legumes to tropical farming systems

5-1-8

NOTICE: THIS MATERIAL MAY BE PROTECTED BY COPYRIGHT LAW. (TITLE 17 U.S. CODE)

L. R. Humphreys

Department of Agriculture, University of Queensland, St Lucia 4067, Australia

PN-AAP-848/62
ISN-34351

The potential for the increased use of pasture legumes in the tropics has excited the imagination of many scientists. Substantial resources have been directed in the past three decades to finding adapted plants and to understanding how these may be incorporated in farm practice [1]. The expectations of these programmes are directed to increased animal production and sometimes to the stabilization of cropping systems.

Legumes and animal production

Legumes improve animal output by providing a better diet, maintaining better continuity of feed supply, or increasing the amount of forage grown. In the tropics grasses tend to have a low nitrogen content and to contain much fibre, at least seasonally. Energy intake of ruminants is limited in a major fashion if the average nitrogen content of the diet is less than *c.* 1.1 per cent: a significant role for the legume is to provide a protein bank which will enable available roughages (crop residues or pasture) to be utilised more efficiently (figures 1, 2, 3). In the past, protein quality has been given little attention in ruminant diets, since so much protein degradation occurs in the rumen. However, the discovery of the importance of 'by-pass' protein, which is utilised more directly further down the digestive tract, has prompted reassessment of this view. Some tropical legumes, for example *Desmodium intortum* cv. Greenleaf, have been criticised for their high tannin content, but it is now thought this may contribute to protein protection. The degradation of protein in the rumen is positively correlated with protein solubility, and there are interesting differences between legume species whose effects on animal performance need to be studied. T. Aii and T. H. Stobbs [2] observed that protein solubility in the leaves of *D. intortum* was 8 per cent compared with 41 per cent for *Macroptilium atropurpureum* cv. Siratro; the comparable figures for stems were 16 and 53 per cent respectively. There is also less seasonal variation in nitrogen content in legumes than grasses, which may in part be associated with the dependence of legumes on rhizobial nitrogen.

Tropical pasture legumes are free of many of the toxicity problems of the temperate legumes. Bloat is a rare occurrence, and farmers may sleep calmly at night whilst their livestock graze legume dominant swards. The problem of oestrogenic potency which has bedevilled the use of *Trifolium subterraneum* has not been encountered in the cultivated tropical pasture legumes. In *Leucaena leucocephala* high levels of mimosine, which cause hair loss and which lead to the goitrogenic substance 3-dihydroxy pyridine [3] as a rumen degradation product have imposed management requirements on the use of this plant. Although this problem of goitre is evident in Australia and in Papua New Guinea, it does not appear in animals grazing Leucaena in Hawaii [4] and Mexico, where a longer history of association between cattle and Leucaena appears to be reflected in different adaptive mechanisms of mimosine degradation. Toxicities may sometimes work to the advantage of domestic livestock; the sticky secretions on the leaves of *Stylosanthes scabra* and *S. viscosa* poison larvae of the cattle tick *Boophilus microplus* [5].

Tropical pasture legumes often exhibit dietary characteristics which are superior to those of the tropical grasses, but the level of digestibility is on average about 4 units below that of the cultivated temperate species [6] at equivalent stages of maturity and this leads to poorer rates of individual animal production. However, the rate of decline in digestibility and in animal intake as pastures mature is much slower in tropical legumes than in the grasses [7], and this helps to sustain production. Continuity of forage production is superior in deep rooted legumes, and a good deal of interest has been directed to shrub or tree legumes which provide high-protein green foliage when grasses have hayed off (see *Gliricidia maculata* in figure 4 and [8]). These may be grown as a special purpose stand or as a 'living fence' and grazed or cut in conjunction with other feeds. In irrigated rice farming systems the sowing of the paddy bund with a legume such as *Stylosanthes hamata* cv. Verano leads to a natural deferment of grazing (since the main area is under crop) and the grazing of the legume-dominant bund in the dry season involves a feed source higher in protein than the low-nitrogen rice straw.

Legumes well nodulated with *Rhizobium* convert atmospheric nitrogen to forms available to the legumes, part of which eventually becomes available to companion grasses. Legumes which nodulate readily and effectively with native *Rhizobium* are preferred by farmers to those with specific requirements. Nitrogen sources based on fossil fuel manufacture are not always conveniently available to tropical countries, and are often used at an artificially subsidised price. Legume nitrogen is regarded as a

Outlook on Agriculture, Volume 11, No. 4, 1982.
(© Pergamon Press. Printed in Great Britain)
0030-7270/82/040144-07 $03.00.

Figure 1 Cattle grazing low-protein, high-fibre rice straw during the dry season in northeast Thailand.

Figure 2 The legume *Stylosanthes hamata* cv. Verano maintains the animal in positive nitrogen balance during the early dry season.

Figure 3 The indeterminate spike of *S. hamata*. The seed pods are high in protein and form part of the grazing animal's diet (Photo: P. J. Argel).

Figure 4 The deep-rooted shrub legume *Gliricidia maculata* provides green forage for dairy cattle in the lowlands of Sri Lanka.

'clean' source by many environmentalists, and a more economic source by many scientists. Much has been written about the declining soil fertility consequent upon the despoliation of the Amazon forests; it is of interest that E. A. S. Serrao and co-workers [10] believe cultivated pastures may improve the chemical properties of these soils if adapted legumes are incorporated, stocking rate controlled, and soil phosphorus levels corrected periodically. The extent of nitrogen donation by tropical pasture legumes is varied enormously by soil and climatic conditions and by management strategies; cut-and-remove systems may interrupt the usual cycle of return of nutrients and cause a spatial dislocation of legume benefits. The gains from legumes vary from no demonstrated response to the sort of increased production reported by J. C. Tothill [11] in the sub-humid subtropics of Queensland, where the addition of *M. atropurpureum* cv. Siratro with superphosphate to natural pastures dominated by *Heteropogon contortus* increased long-term cattle output by factors of *c.* 1.3 and *c.* 4.1 on a per head and per hectare basis respectively.

Legumes and cropping systems

Soil-exhaustive cropping systems are a continual feature of many tropical landscapes. There is a constant challenge to technology to provide new solutions to problems created by increasing population pressures on the land, which may shorten the cycle of bush-fallow systems, bring marginal lands into cultivation, and change cropping patterns towards crops adapted to low fertility levels (for example, cassava) and capable of further depleting soils whose fertility was previously depleted by monoculture of maize or other crops. The conventional approach of ley farming, in which a cropping phase is alternated with a legume-based pasture phase, has not been adopted by farmers of the tropics and is prominent only in text books. At the same time, there are many intensively cultivated areas with a high animal density. Cultivation and farm traction may be by draught animals, in which case crop and animal welfare are interdependent, or animals may play a significant role in the use and the cycling of crop residues and of volunteer pasture on areas unsuited to cultivation.

There are three types of cropping situation where tropical pasture legumes are contributing significantly to the maintenance of soil fertility and to the stability of the system. The first is where plantation crops have a leguminous cover developed (figure 5) or a pasture containing legumes as the understory. Pastures diversify income; minimise weed problems; prevent soil erosion; and improve soil physical characteristics, whilst some nitrogen accretion may be expected if the legume content is sufficient. Pastures under coconuts are successful in many tropical countries. Inadequately fertilized pastures based on particular grasses may reduce coconut yield or yield may be unaffected. In west Bali, K. Rika and co-wokers [12] found that well-grazed pastures of *Brachiaria decumbens* containing *c.* 20–30 per cent *Centrosema pubescens* with *M. atropurpureum* cv. Siratro increased nut yield *c.* 50 per cent relative to volunteer pastures; live weight gain of 550 kg per ha per year might be expected from a stocking rate of five *Bos banteng* yearlings per ha. The second situation is where the forage legume constitutes the shrub or tree crop. There is increasing demand for multiple-use legume crops which contribute cut legume shoots for forage, wood for fuel and for light construction work, and leaf drop to maintain soil fertility. *L. leucocephala*, *Sesbania grandiflora* and *S. aculeata*, *G. maculata*, and *Albizzia* spp. are preeminent in differing soil situations. In India the trees may be inter-cropped with annual food or cash crops [13]. Finally, herbage legumes may be planted with annual crops, and the competitive balance manipulated by attention to delayed sowing time and control of plant density so that the yield of the food or cash crop is not reduced [14].

Successful and unsuccessful plantings

The laudable objectives discussed to this point have been realised only in a minority of farm situations. In some countries tropical pasture legumes do play a significant role in increasing agricultural production. In Queensland, Australia, there are substantial areas of humid coastal and tableland pastures containing *M. atropurpureum* cv. Siratro, *Neonotonia wightii*, *Stylosanthes guianensis*, and *Centrosema pubescens* and of drier areas with appreciable *S. humilis* and *S. hamata*, but only a minor proportion of the total improved pasture area of 3.2M ha [15] has an effective legume component. In Cuba there are considerable pasture areas containing *N. wightii* and *C. pubescens*. In northeast Thailand *c.* 60,000 ha was sown to *S. hamata* cv. Verano in the past five years; communal roadside areas, which provide 2 to 4 ha of grazing per km of developed road, have been included in this programme. Throughout southeast Asia the prostrate, diminutive *D. triflorum* is abundant in this situation.

In many other territories—southern U.S.A., Latin America including Brazil, west and east Africa—the main thrust of pasture development has been the use of improved grass species, with or without fertilizer nitrogen, despite some active legume research programmes. Attention to legumes has been considered misplaced by some critics [16] and many instances of the fragile character of legume technology when transferred to another country have disillusioned landholders about the feasibility of incorporating pasture legumes in a permanent way into their farming systems.

Persistence of legume yield

The paucity of detailed ecological studies about the distinct pathways of persistence of tropical legumes has been one factor contributing to the difficulty of formulating research and management programmes which would overcome this problem. The failure of legumes may be associated with the longevity of the original population; with the development of autonomous plants from vegetative buds with roots; or with the cycle of plant replacement through flowering, accretion of soil seed reserves, seedling regeneration, and seedling survival.

Plant replacement has little importance for the perennial shrub legumes; 87 per cent of individual plants of *L. leucocephala* were surviving after 16 to 20 years of grazing in southeast Queensland [17]. On the

3

other hand, many apparently perennial herbage legumes with strong rootstocks are quite short-lived. *M. atropurpureum* cv. Siratro plants had a half-life of 15 months if grazed at 1.7 beasts per ha, or only 5 months if grazed at 3 beasts per ha [18]; hence management may also influence longevity and the relative importance of particular pathways of persistence. *S. hamata* cv. Verano and *Lotononis bainesii* are also short-lived but persistence in other legumes has not been studied in detail.

The replacement of dead shoots with new rooted shoots initiated on perennating stem tissue is the second pathway of persistence, and is common amongst creeping legumes such as *Arachis glabrata* cv. Florigraze (Rhizoma Peanut) [19] or in humid conditions amongst twining, stoloniferous legumes such as *M. atropurpureum* cv. Siratro and *N. wightii*. Separate stem sections become autonomous and detached from the mother plant. In A. Pott's studies [20] *L. bainesii* plants developed from stolons were more resistant to sheep treading than seedlings, but these vegetative survivors from nodal roots were of less significance than seedlings in contributing to the persistence of yield.

The cycle of seedling regeneration and maintenance of soil seed reserves is crucial for short-lived plants; it is also necessary to the ecological success of longer-lived plants if intermittent hazards to which they may be susceptaible (such as flood, fire, or very heavy grazing), occur. We are gradually accumulating a better understanding of the climatic factors which control flowering and seed formation in the main cultivated tropical pasture legumes. Most of these are short-day plants, exhibiting either qualitative or quantitative responses. For example, the variation in the earliness of flowering of *S. guianensis* lines is mainly related to a differing requirement for duration of short-days [21]; this is modified by interaction with temperature. Recently, long-short day plants (flowering requiring long days before plants are exposed to short days) have been discovered in *S. guianensis* [22]. Seedlings have a varying juvenile phase before short-days will evoke flowering; this phase is well developed in *S. guianensis* but not in *S. humilis* or *S. hamata* cv. Verano. This type of information contributes to our understanding of the climatic zones to which particular lines are adapted, and to the selection of sites suitable for seed production.

Hardseededness is the most persistent form of dormancy which contributes to the longevity of legume seed reserves in the soil. The extent of hardseededness is sensitive to provenance. In *S. hamata* cv. Verano seed moisture content is the predominant factor controlling hardseededness, but hardseededness is also positively related to temperature after flowering, during seed formation [23]. Seeds formed under high temperature have higher contents of lignin in the counter-palisade cells of the hilum and a more regular and organised seedcoat structure. On the other hand the breakdown of legume seed dormancy in soil may be less rapid in the cooler sub-tropics [24]. Legume seed reserves under grazed swards can be as high as 10 000 seeds m^{-2}, and this substantial bank may be drawn upon by cultivation or fire to promote seedling regeneration. In heavily grazed situations the prevention of flowering or the consumption of inflorescences may limit seedling replacement via the constraint of seed reserves.

Strategies for more successful adaptation

The adaptation of pasture legumes to managed farm environments requires persistence of yield of digestible nutrients; nitrogen accretion from nodulated legumes will be closely related to dry matter production. Plants may be thought of as successful either because they survive the hazards of an environment better than other plants, tolerating stresses actually experienced or avoiding these, or because they win a larger share of environmental growth factors, interfering with the availability of these to companion plants.

Tropical legumes are usually at a disadvantage relative to grasses. The C_3 legumes lack the growth potential of the C_4 grasses, except under conditions of soil nitrogen deficiency or where they overtop companion grasses and deny them light. The cultivated tropical grasses currently exhibit a wider range of adaptation to almost all environmental hazards than the legumes, whether these hazards are predominantly biotic (grazing, burning, diseases, and pests); edaphic (toxicities, salinity, soil fertility); physiographic (flooding, drainage); or climatic (drought, heat, cold). Nevertheless considerable advances have been made in domesticating legumes which widen the environmental conditions under which legumes may be planted and there is great genetic potential yet to be exploited. Within the genus *Stylosanthes* farmers are planting *S. hamata* cv. Verano in areas receiving 400 mm annual rainfall and *S. guianensis* in 3000 mm areas. The annual *Centrosema pascuorum* shows promise in low rainfall monsoon areas, *C. pubescens* is grown in the warm humid lowlands, whilst *C. virginianum* extends to cold districts at lat. 41°N. in the U.S.A.

Resistance to grazing and cutting. A major cause of legume failure and of lack of farmer adoption of legumes is the lack of resistance to grazing exhibited by the tropical legumes of twining, scrambling, or erect habit. These plants do not usually persist in humid areas where the year-round stocking rate exceeds *c.* 2.5 beasts ha^{-1} and lack the avoidance capacity of creeping plants whose low-set stem buds and basal leaves are below the reach of the jaws of grazing animals. Farmers are unwilling to accept or understand the need for the low stocking rates dictated by this type of response.

Some advance has been made through selection for grazing resistance; an alternative approach is the seasonal use of pastures in accord with the requirements for plant replacement. An instructive recent example comes from the work of R. C. Gutteridge [25] in northeast Thailand, where a feed shortage for ruminants can exist during the wet season when much of the land is being cropped. Pastures were grazed from June to November inclusive; under this system the twining legume *M. atropurpureum* cv. Siratro (figure 6) proved resistant to heavy grazing, since the main flowering and seeding period occurred

Figure 5 *Desmodium intortum* cv. Greenleaf as a leguminous cover in young *robusta* coffee in the hills of northern Thailand.

Figure 6 Right: *Macroptilium atropurpureum* cv. Siratro flowering and twining on a bamboo grass.

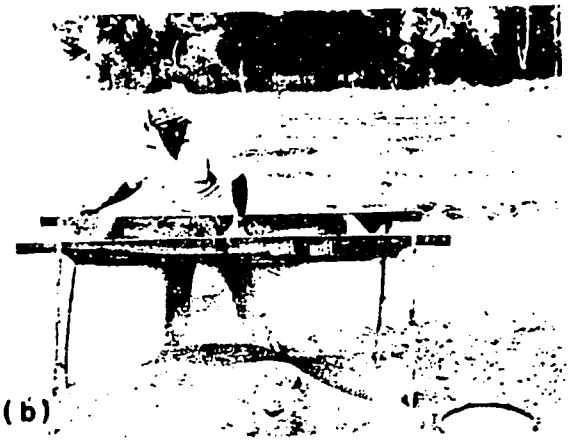

Figure 7 Smallholder seed production of *S. hamata* in northeast Thailand.
(a) The tops are hand cut and raked off (back right). Seed and soil are scraped into windrows.
(b) Stem and trash are removed with a 3 mm screen.
(c) Soil is removed with a 0.5 mm screen.
(d) The lower articulation is rubbed out of the spike by sandalled feet and the clean pods winnowed subsequently by shaking the bamboo pans.

in December and January which enabled some recovery growth and replenishment of seed reserves to occur. A further factor was the tallness of the companion grass, which offered less competition for light to a twining legume than to a short-statured plant like *S. hamata* cv. Verano. Similarly, but in other situations, the earlier flowering *S. hamata* cv. Verano was grazed early in the main growing season in July-August at rates of up to *c.* 500 grazing days ha^{-1} without detriment to seed yield [26].

Resistance to pests and disease. The need for agronomists and plant breeders to work with plant pathologists and entomologists to overcome problems of tropical legume susceptibility to disease and to pest attack has become increasingly evident in the past decade [27]. Plants brought from one continent to another without their natural parasites have performed well for decades, but the rupturing of geographical isolation through trade and travel has led to some devastating outbreaks. *S. humilis* was spread over several hundred thousand hectares of northern Australia before *Colletotrichum gloeosporioides* (Anthracnose) severely reduced its productivity. Many pasture legumes introduced and selected on the basis of their superior performance in Queensland proved dismal failures when exposed to the spectrum of diseases and pests of their native Latin America.

Many scientists believe the search for genetic resistance (which is the most appropriate approach for low-value pastures) is best conducted in the original centres of diversity of the plants under consideration, and this has led to expanded efforts in Brazil and Colombia [28] and to germplasm collection and collaborative testing in adjacent regions. At CIAT (Centro Internacional por Agricultura Tropical (Colombia)) resistance to anthracnose has been found amongst promising lines of fine-stemmed, viscous late flowering *S. guianensis*, of *S. capitata*, and of *S. macrocephala*. The continued evolution of the Anthracnose complex and the appearance of new virulent races in this and other pathogens will no doubt provide employment for future races of scientists.

Adaptation to acid soils. The soils of the tropics are noted for their widespread acidity, and tropical pasture legumes exhibit considerable diversity in their adaptation to the different problems associated with soil acidity. For example, D. N. Munns and R. L. Fox [29] found that on a Hawaiian oxisol the level of calcium carbonate required to produce 90 per cent of maximum yield in a suite of legumes varied from 11 t ha^{-1} in *L. leucocephala* to 0.1 t ha^{-1} in *S. guianensis*. It is feasible in many farm situations to apply low levels of calcium as a nutrient; it is extremely difficult to modify the pH of the subsoil. Research emphasis has been concentrated on locating legumes tolerant of low pH and on defining the nature of the acidity problem in different farming systems and localities. This problem may reflect direct effects of low pH, low availability of nutrients such as calcium and molybdenum, and toxic levels of aluminium, and manganese. Within the one genus species show a range of response; for example *S. guianensis*, *S. scabra*, and *S. viscosa* were less tolerant of aluminium excess than *S. hamata* and *S. fruticosa* in a study by M. M. de Carvalho and her co-workers [30]. Nitrogen fixation is more sensitive to aluminium toxicity than is legume growth with adequate combined nitrogen available, and the varying capacity of legumes to nodulate and actively fix nitrogen on acid soils is a primary criterion of merit in many regions.

Selection programmes are also actively directed to other environmental hazards mentioned earlier which limit the ecological niches into which legumes can be readily introduced.

Legume seed production

The expansion of farm sowings of tropical pasture legumes requires the continuous availability of seed of reliable quality and reasonable price. The uncertainties of international trading and fluctuations in demand have not helped the development of specialist export industries in this field, although there have been considerable advances in the technology of legume seed production, harvesting, and processing [31]. On the other hand there are notable examples of local initiative in the production of seed of new legume varieties.

These ventures have not necessarily required inputs of sophisticiated machinery, and high yields of seed of excellent quality have resulted from labour-intensive systems once research has provided the basic technology for production. One such example is the production of *S. hamata* cv. Verano seed in northeast Thailand. The Thai Department of Livestock Development originally foreshadowed a major legume seed production enterprise on government stations, but it was found that production by smallholders was more feasible and efficient. Production increased over a 5-year period until, in 1981, 187 tonnes of Verano seed was supplied by 1131 individuals, many of whom worked cooperatively or as families. The average yield was 910 kg ha^{-1} [32]. This high yield was achieved through attention to seed bed preparation, adequate sowing density, and the correction of soil sulphur and phosphorus deficiencies, and occurred in a region to which Verano is well adapted. Harvest and processing techniques are shown in figure 7.

Attention needs to be given to defining the various sectors of farming systems in which pasture legumes may make a specific contribution to animal production and/or to the stability of cropping systems, and to identifying the legume germplasm which can be incorporated most effectively in these diverse situations. The development of these plant materials requires greater attention to plant collection and evaluation, and to more inter-disciplinary studies of the processes involved in the successful adaptation of legumes to environmental stresses. The ready availability of seed of elite pasture legumes suitable for use in the diverse farming conditions of the tropics is counted the single innovation most likely to sustain gains in productivity.

References

[1] Humphreys, L. R. 'Environmental Adaptation of Tropical Pasture Plants'. Macmillan, London, 1981.

[2] Aii, T., and Stobbs, T. H. *Anim. Feed Sci. Technol.* 5, 183, 1980.

[3] Hegarty, M. P., Lee, C. P., Christie, G. S., Court, R D., and Haydock, K. P. *Aust. J. Biol. Sci.* **32**, 27, 1979.
[4] Jones, R. J. *Aust. Vet. J.* **57**, 55, 1981.
[5] Sutherst, R. W., Jones, R. J., and Schnitzerling, H. J. *Nature, London*, **295**, 320, 1982.
[6] Wilson, J. R., and Minson, D. J. *Trop. Grassl.* **14**, 253, 1980.
[7] Milford, R. *Aust. J. exp. Agric. Anim. Husb.* **7**, 540, 1967.
[8] Chadhokar, P. A., and Lecamwasam, A. *Trop. Grassl.* **16**, 46, 1982.
[9] Gutteridge, R. C. *Summaries 14th Int. Grassl. Congr.*, **75**, 1981.
[10] Serrao, E. A. S., Falesi, I. C., de Veiga, J. B., and Neto, J. F. T. 'Pasture Production in Acid Soils of the Tropics'. Sánchez, P. A., and Tergas, L. E. (eds), p. 195. CIAT, Cali, Colombia, 1979.
[11] Tothill, J. C. *CSIRO Aust. Trop. Crops Past. Div. Rept.* 1976–77, 32, 1977.
[12] Rika, K., Nitis, I. M., and Humphreys, L. R. *Trop. Grassl.* **15**, 149, 1981.
[13] Patil, B. D. *Proc. 14th Int. Grassl. Congr.* (in press), 1982.
[14] Shelton, H. M., and Humphreys, L. R. *Expl. Agric.* **11**, 103, 1975.
[15] Queensland Dept. Primary Industries. Sown pastures and seed production in Queensland. 1981.
[16] Boonman, J. G. *Summaries 14th Int. Grassl. Congr.*, **210**, 1981.
[17] Jones, R. M., and Harrison, R. E. *Trop. Agric.* **57**, 265, 1980.
[18] Jones, R. J., and Jones, R. M. 'Plant Relations in Pastures'. Wilson, J. R. (ed.), p. 353. CSIRO, Melbourne. 1978.
[19] Prine, G. M. *Summaries 14th Int. Grassl. Congr.*, **60**, 1981.
[20] Pott, A. Ph.D thesis, Univ. Qld 979.
[21] Bryant, P. M., and Humphreys, L. R. *Aust. J. Exp. Agric. Anim. Husb.* **16**, 506, 1976.
[22] Ison, R. L. Ph.D. thesis, Univ. Qld. 1982.
[23] Argel, P. J., and Humphreys, L. R. *Proc. 14th Int. Grassl. Congr.* (in press), 1982.
[24] Jones, R. M. *Trop. Grassl.* **15**, 95, 1981.
[25] Gutteridge, R. C. Ph.D. thesis, Univ. Qld. 1982.
[26] Wilaipon, B., and Humphreys, L. R. *Thai J. Agric. Sci.* **14**, 69, 1981.
[27] Lenné, J. M., Turner, J.W., and Cameron, D. F. *Trop. Grassl.* **14**, 146, 1980.
[28] C.I.A.T. *1979 Trop. Past. Prog. Ann. Rept*, 1980.
[29] Munns, D. N., and Fox, R. L. *Pl. Soil* **46**, 533, 1977.
[30] Carvalho, M. M. de, Andrew, C. S., Edwards, D. G., and Asher, C. J. *Aust. J. Agric. Res.* **31**, 61, 1980.
[31] Humphreys, L. R. 'Tropical Pasture Seed Production'. FAO Pl. Prodn. Protn. Pap. 8, Rome. 1979.
[32] Thai Dept. Livestock Development. Northeast Livestock Development Project 12th Rept to IBRD, Khon Kaen, Thailand, 1981.