THE APPLICATION OF AUSTRALIAN TROPICAL PASTURE TECHNOLOGY TO ASIA AND THE PACIFIC
— Review —

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Summary

The grassland regions of Australia, the Pacific and Asia share common latitudes albeit in opposing hemispheres. However, the environmental and socio-cultural context of pasture development in the subtropical and tropical regions of Australia, the Pacific Islands and Asia differ greatly. Successful technology transfer for improved productivity of grazing livestock is beset by three broad challenges; technical, logistical and socio-cultural. The technical challenge of defining the grassland environment and adapting known technology to local conditions can be successfully addressed by local technicians supported by a reservoir of appropriate international expertise. Logistical difficulties that impede provision of infrastructure and continuity of support services are the responsibility of indigenous organisations. Socio cultural factors are fundamentally pervasive. These challenges, though outwardly obvious, require careful consideration by both donors and recipients of pasture technology to ensure success with pasture development for viable grazing industries.

(**Key Words**: Pasture, Technology, Development, Improvement, Grazing, Production)

The socio-cultural context of pasture development

1) Australia

In northern Australia, intensive pasture production occurs only in limited favoured sites in humid coastal climatic regions. The vast area of grazing lands principally occurs in the continental hinterland and is operated using extensive management practices (Shaw and Norman, 1970). Climatic conditions are characterized by a summer monsoonal influence, a wide temperature range, and a discrete and prolonged dry season, especially in the lower latitudes (Gentilli, 1971). Soils are of ancient derivation and severely weathered, typically mildly acid, and low in phosphorus (Leeper, 1973).

In the extensive grazing regions, economic units vary in size from c. 20,000-600,000 ha, land tenure is freehold or leasehold, and economic performance depends on minimal labour and low-cost operating practices (Davidson, 1981). The Australian perspective, shaped by economic circumstances, is to adopt low-cost approaches to development; least initial investment and minimal maintenance systems. This is achieved by developing only the better soils, avoiding heavily timbered areas, and seeding with low fertilizer-requiring legumes. The introduction of improved grasses requires additional resources associated with seed-bed preparation, but where undertaken, provides improved feed supply by extending the period of green feed in the wet season and improving botanical stability.

The northern Australia beef cattle industry is supported by a reservoir of agronomic and livestock expertise based on over 100 years of grazier and extension activity, 60 years of plant introduction and evaluation work, and 45 to 50 years of multi disciplinary agronomic research (Eyles et al., 1985a). Research has continued to contribute new and improved technology including new species, pasture establishment techniques, fertilizer programs, and grazing management strategies. Pasture research is acknowledged to be an important factor in the continuing development of the Australian pastoral industries. Economic studies have assessed the cost/benefit

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relationship for agricultural research as highly cost effective (Davidson, 1981; Tribe, 1989). Typically, research has evolved uniquely Australian low-cost grazing technologies aimed at increasing productivity by improving the efficiency of resource use.

2) Pacific Islands

Pacific Island nations with a significant incidence of pasture development are located in humid subtropical/tropical regions that in the main experience favourable conditions due to maritime climatic influences. The temperature range is narrow (typically less than 10℃) and rainfall is high. However, soil water holding capacity of island soils can be notoriously low due to shallow soil depth and low bulk density. Moreover, coralline soils overlain with a shallow layer of volcanic ash are acutely fragile and vulnerable to degradation following disturbance.

For Pacific Island people the role of grazing enterprises is to complement the more profitable export earning industries like coconut products, root crops, tropical fruit and handicrafts, and to contribute to material self-reliance. Agricultural activity, though, is dominated by traditional subsistence farming of food crops like taro, cassava, coconut, breadfruit, yam, fruit and vegetables. Livestock including poultry, pigs and cattle are maintained principally under "smallholder" husbandry systems.

Socio-cultural factors have been a significant obstacle to the implementation of pasture technology and broadacre grazing. In some instances there has been experience with pasture development for some 30-40 years and a unique complementary production system "cattle under coconuts" has evolved (Reynolds, 1981). Traditional family or clan rights to land ownership and the "social obligation system" are culturally pervasive and have impeded both a commitment to investment in agricultural development and success with broadscale operations; there is a close association between security of land tenure and willingness to invest in long term agricultural activities (Faletau and Hardaker, 1988).

In addition to overt socio-cultural factors, Pacific Island nations face two significant problems:

(1) The economic problem of adapting smallholder operations into an industry that for profitability demands efficient vertical integration of production, processing and marketing arrangements but where the scale of operations is both small and remote from the export market place.

(2) The logistical problem of maintaining an ongoing commitment of capital, labour and management resources to sustain productive pastures (Steel et al., 1980). However, where broadscale "estate" grazing operations have been successfully implemented (e.g. Vanuatu), both pasture management and cattle husbandry are superior to traditional systems, and there is apparent scope for integration of both sectors into a close economic unit (Macfarlane and Shelton, 1986).

In early pasture enterprises, success has been limited by attempts to directly transfer temperate pasture technology (e.g. intensive seed bed preparation, legume monoculture cover-cropping, rotational grazing) into tropical environments, and failure to incorporate "rebustness" into pasture systems (Ayres, 1985b). From a technology perspective, the technical challenge is not prohibitively difficult provided that the practices applied derive from the reservoir of international tropical grasslands expertise and are adapted sensitively to local conditions.

3) Asia

Subtropical and tropical Asia including southern China, Taiwan, and the countries of Indo-China share latitudes in common with Australia, albeit in opposing hemispheres. The Malaysian peninsula and the archipelagoes of Indonesia and the Phillipines are equatorial, while northern China, Japan and Korea located in the high latitudes share temperate climatic conditions. The general climatic influences that operate in subtropical/tropical Asia are twofold; a tropical maritime influence in summer, and a polar transcontinental influence in winter (Kendrew, 1961). The maritime influence brings a moisture-laden warm southerly airstream with rainfall in summer, while in the winter months polar air originating in Central Asia brings dry cold northerly winds. The interaction of these opposing systems produces the characteristic monsoonal climate of south-east Asia.

Pasture development experience in southern China. Homoclimes in northern Australia and southern China provide potential for transfer of pasture technology through identifying and matching similar grassland environments.

Historically, due to population pressure and the traditional system of land use, only "the wastelands" (adverse sites unsuited to either padi culture, dryland cropping, plantation agriculture or forestry) are utilized for pasture development. Wasteland habitats are typically vegetated with disclimax communities in transition from "weeds-of-cultivation" to shrub ingress, tree regrowth and softwood jungle. The combination of denudation of native forest vegetation due to "slash and burn" and shifting cultivation, together with a historical disregard for the condition of non-irrigable land has led to loss of much surface soil from erosion. Wasteland soils can be severely degraded, depleted of the organic matter horizon, strongly acid and with high levels of aluminium saturation. Historically, the wastelands have been subjected to multiple land use by villagers for a variety of subsistence activities, including shifting cultivation, shepherded grazing, fuel and food gathering, quarrying and hunting.

The traditional grazing system is based on night-time shedding combined with shepherding cattle in daylight hours on preferred areas within close walking distance of cattle sheds. Before the advent of Australian projects from *ca.* 1980, there was little infrastructure to assist husbandry, neither fencing nor adequate handling systems to facilitate cattle husbandry, and no improved pastures (Ayres, 1983a). Despite the incidence of severe animal health problems, particularly with parasites (ticks, screw worms, buffalo fly, internal parasites) and the unhygienic conditions imposed by night-time shedding, preventative health care is minimal. Typically, neither weaning nor castration are purposely practised, and cows calve year-round in response to increase in body condition coinciding with a seasonal flush in feed conditions. In short, husbandry practices are rudimentary with major concessions to people convenience rather than the nutritional and management requirements of livestock.

Production of beef and dairy livestock is consequently limited by an inadequate supply of pasture feed, especially in winter, compounded by traditional night-time shedding that severely restricts grazing time. Cattle are stunted, unproductive in growth and reproductive performance, and susceptible to "winter-stress". Pasture conditions can be so acutely deficient during winter as to impose a routine dependence on handfeeding with rice straw, sweet potato leaf or other available crop by-products and agricultural refuse (Ayres, 1985a). The solution is to provide an improved feed base through pasture development technology coupled with development of farm infrastructure to facilitate the implementation of progressive husbandry and strategic grazing management (Ayres, 1983b).

Since about 1980, profound changes have occurred in the organization of agricultural production in China. These changes have resulted in modification of the "collective" operation of the commune system to new economic associations termed the "individual responsibility" system (Nalson and Ayres, 1984). The individual responsibility system has been promoted as a means of taking advantage of economies of scale and co-operative associations to increase labour efficiency and agricultural productivity. Coincidentally, it is from this period that efforts to introduce Australian pasture technology commenced and subsequently intensified.

From the outset, pasture development in southern China experienced social and organizational conflicts arising from (i) government initiatives to develop agricultural productivity for the future, and (ii) the response of local people to the new measures of "individual responsibility" designed to immediately increase production (the classical "bread now, cake later" dilemma). In practice, conflicts occurred due to a combination of historical factors with; (a) the changes occurring in commune and local government organizations, and (b) the expectations of local people under the "individual responsibility" system (Nalson and Ayres, 1984). These conflicts imposed difficulties for the conduct of pasture development including delays with land surveys and negotiations over land use entitlements, diversion of project budgets to compensation claims, and loss of timeliness with development operations. A further variation on this theme of "bread now - cake later" as experienced in north-central China is resistance to adoption of lucerne (*Medicago sativa*) culture [which has proven local benefits from reducing soil erosion and increasing livestock and crop productivity] because of the preference of subsistence farmers to allocate scarce resources to cash crops like tobacco (Chen Wen et al., 1992).

Notwithstanding these impediments to progress, where transfer of pasture technology has been supported by local adaptive research, outstanding results have been achieved. Michalk et al. (1984, 1986) report a sevenfold increase in beef production associated with pasture development and improved cattle husbandry. These results compound increases of some 400 percent in carrying capacity, 50 percent in calving rate, 90 percent in calf growth rate to weaning, and a 20 percent increase in mature body size. These workers, however, caution that a number of local factors continue to mitigate against widespread adoption of pasture technology; namely, limited capital and scarce resources, inadequate processing and marketing arrangements, land use conflicts, paucity of local expertise, and the problem of extending pasture technology from government controlled state farms to the communely operated wastelands.

Principles of pasture development

Although animal husbandry is one of the most ancient forms of agriculture, cultivated grasslands are a relatively modern development. Only fodder legumes like lucerne and red clover (*Trifolium pratense*) were used in ancient times. Pasture improvement had its foundations with the development of clover ley farming in Europe in the 18th Century, but was only of minor importance until progress with agricultural chemistry in the middle of the 19th Century led to breakthroughs in knowledge of soil fertility and bacteriology to explain the significance of the symbiotic association of rhizobium and legumes. From the early 20th Century, the dual practice of white clover (*Trifolium repens*) and phosphate fertilizer were combined to consolidate a stable and productive land use system, and improved sheep and cattle production from fertilized white clover pastures were clearly demonstrated (Stapledon and Davies, 1941).

By contrast, native vegetation on unimproved land provides a poor feeding regime for grazing animals. Tree and bush communities offer little nutritious feed, and moreover, limit the growth of undercanopy forage species. Native species are *ipso facto* well adapted to local conditions but are deficient in characteristics important for grazing production. Typically, native species are short season. Annual grasses proceed rapidly through their growth cycle to set seed within as short an interval as six weeks. Perennial grasses flower and set seed early in the wet season and present mature coarse forage residues for most of the year. Native legumes rapidly proceed to podding and shed foliage before onset of the dry season.

The advantageous features of improved tropical pasture species are; (i) increased yield potential, (ii) superior nutritive value, and (iii) capacity to extend the growing season and retain green leaf through the dry season. Species with these attributes have been developed through programs of plant collection, selection and field evaluation. Representative samples of many thousands of cultivars are held in genetic resource centres by scientific agencies and provide a gene pool for selection and breeding. Superior cultivars are released periodically for commercial use.

Improved tropical grasses possessing the C4 photosynthetic pathway are potentially higher yielding than temperate C3 species due to higher photosynthetic rate, higher net assimilation rate, non-detectable photorespiration, and low intra-cell resistance to carbon dioxide. Tropical grasses make more efficient use of water and nitrogen. In general, tropical grasses and legumes combined are higher yielding than in monoculture, and very high yields can be obtained from nitrogen fertilized grass (table 1). Exceptionally high yields of pasture legumes in monoculture have also been reported; *Desmodium intortum* (dry land) - 17,600 kg ha^{-1}, *Leucaena leucocephala* (dry land) - 12,600 kg ha^{-1}, *Macroptilium atropurpureum* (irrigated) - 24,000 kg ha^{-1}, *leucaena* (irrigated) - 39,000 kg ha^{-1}, *Desmanthus virgatus* (irrigated) - 64,000 kg ha^{-1} (Jones 1976).

1) Pasture Improvement

The major factor in the innovation of grazing systems in Australia has been the contribution of pasture improvement, namely the dual practice of sowing adapted pasture legumes and topdressing with phosphate fertilizer. Each additional hectare of sown pasture in Australia has increased the national sheep flock by about 4 sheep equivalents (Donald, 1967).

Pasture improvement can take the form of partial or complete relacement of native species

TABLE 1. YIELD (KG HA⁻¹) OF LEGUME*, LEGUME/GRASS* AND NITROGEN FERTILIZED GRASS* AT VARIOUS LOCATIONS IN NORTHERN AUSTRALIA (SOURCE: COLMAN, 1971)

Location	Adapted legume	Legume /grass	Grass* nitrogen
Lismore (28 ° S)	5,200	6,200	20,000
Lawes (27 ° S)	4,100	8,600	—
Samford (27 ° S)	5,450	12,500	20,800
Beerwah (27 ° S)	1,890	4,100	24,200
Howard (25 ° S)	6,700	—	13,300
Townsville (19 ° S)	4,600	10,000	—
S. Johnstone (17 ° S)	11,200	—	—
Atherton (16 ° S)		—	11,000

* These data summarise results from numerous trial sites at each location. Within location, species may differ across columns, but all data is for adapted species.

by introduced species. Partial replacement involves incorporation of a suitable species (usually legume but sometimes grass) into an existing plant community with minimal disturbance. Complete replacement typically requires elimination of the existing plant community to make way for a complement of introduced legume and grass species. The correct degree of species replacement is determined by the level of intensification required, site factors, and the availability of resources (capital, fertilizer, machinery). For example, the following pasture development systems for the dry tropics differ in the degree of disturbance to the existing soil and plant community, maintenance costs, and potential for animal production:

(1) Native pasture + phosphate fertilizer ··· undisturbed plant community

(2) Native pasture + phosphate fertilizer + broadcast legume ··· partial replacement system

(3) Stylo/buffel + phosphate fertilizer (low rate) ··· low cost complete replacement system

(4) Siratro/setaria + phosphate fertilizer (high rate) ··· high cost complete replacement system.

A complete replacement system achieves a highly productive pasture from the season of establishment. However, there are certain constraints. Complete replacement systems require arable sites, timeliness of operations, and there is a requirement for mechanization and substantial resources. There is usually an immediate requirement for additional livestock to provide for the grazing management requirements of the developing pasture. For most soils there is a continuing requirement for phosphate fertilizer to maintain persistence of the legume and vigour of the companion grass. A complete replacement system is highly productive, yet there may be significant financial risks associated with the additional resource requirements (Buggie, 1980; Vernon, 1984).

A partial replacement system can be expected to achieve a moderately productive pasture in the medium term (3-5 years). A partial replacement system is normally applied to extensive grazing operations where mechanization is available for trafficable terrain and aerial methods can be utilized on steep or inaccessible hill country. Successful pasture establishment demands rigorous suppression of competition from indigenous vegetation by either soil disturbance, fire or herbicide. There may be logistical difficulties with clearing, burning, scrub regrowth control, fencing, and stock water provision associated with a large scale extensive pasture development operation.

In practice, pasture development integrates areas of improved pasture on the most accessible and best soils with residual areas of native pasture on less favoured sites. An integrated pasture system provides flexibility for efficient use of resources and optimal management. The improved pasture area serves as a source of high quality feed for livestock with priority feed requirements. The component technologies of pasture improvement (species introduction, establishment techniques, fertilizer program, grazing management strategy) are determined through experimentation and refined with experience at each location where climate, soil type and existing vegetation significantly differ.

2) **Plant introduction and merit testing**

The broad objective of a plant improvement program is to introduce and select new pasture cultivars to increase grazing production. Because a cultivar usually has a narrow range of adaptation to environmental conditions, the task in an untested environment is to identify cultivars that are adapted to local conditions and that have superior characteristics relevant to local use. To be successful, introduced cultivars need to be productive and persistent under grazing, increase animal production compared with indigenous species, and produce adequate seed for propagation and seed multiplication purposes. In new environments, a systematic approach is followed to (i) access appropriate germplasm material, (ii) understand the mechanisms of agronomic performance and persistence, and (iii) select superior cultivars. Although there is no universal system, most evaluation programs are based on a generalized system that includes, (i) accessing germplasm, (ii) characterizing the collection, (iii) nursery assessment, (iv) sward assessment, (v) grazing evaluation and (vi) practical demonstration (Ivory, 1986). The relative performance of candidate cultivars is compared on characteristics relevant to agronomic performance and grazing value.

(i) Northern Australia. On the Australian continent, there is a general absence of indigenous legumes possessing characteristics necessary for success as pasture plants (Hutton, 1974). Pasture and fodder legumes came to Australia through deliberate importation by early settlers, and by accidental introductions (Cocks et al., 1978). Overgrazing of the native vegetation led to replacement of native grasses by exotic legumes that rapidly became widely naturalised:

(1) Subterranean clover (*Trifolium subterraneum*) and medics (*Medicago spp*) in southern Australia

(2) White clover in east-coastal Australia

(3) Townsville stylo (*Stylosanthes humilis*) in northern Australia.

White clover was first purposefully introduced into the subtropics with plantings of paspalum and kikuyu in the 1890's (Ostrowski, 1972). More recent introductions include cv. Ladino (1920's), cv. Huia (1950's) and cv. Haifa through the 1970's (Archer and Gresser, 1979). These cultivars have naturalised and hybridized to form ecotypes; for example, Clarence ecotype (O'Brien, 1970; O'Brien and Cohen, 1972). White clover is now naturalised throughout the coastal plain, subcoastal plateau, and hinterland of eastern Australia. Townsville stylo was accidentally introduced into northern Australia through the port of Townsville in the early years of this century and by 1945 had become widely naturalised (Shaw, 1961). Pasture development in the Australian tropics commenced in earnest from the 1930's with centro (*Centrosema pubescens*), peuro (*Peuraria phaseoloides*), calopo (*Calopogonium mucunoides*), and stylo (*Stylosanthes spp*) legumes, and in the subtropics from the 1950's with plantings of siratro, desmodium (*Desmodium spp*), glycine (*Neonotonia wightii*), lotononis (*Lotononis bainesii*) and leucaena.

With the establishment of a government Plant Introduction Service in 1930, species introduction in contemporary times has been by purposeful design. The introduction of pasture plants into northern Australia has been by (i) accessing international germplasm collections, (ii) major plant collecting expeditions and (iii) opportune collecting (Eyles et al., 1985b). The methodology of collection has relied on existing knowledge of plant geography, climatology, taxonomy and adaptation to determine homoclimes in overseas countries. Major emphasis has been placed on pasture legumes and targeting plants of potential value to specific pasture problems. Today, the Australian collection of tropical pasture species is the largest in the world with about 25,000 accessions representing 2,100 species (Williams, 1990). The northern Australian plant introduction and evaluation program has led to release of some 97 registered cultivars to the grazing industries (Mears and Partridge, 1985). There are some 4.5 million hectares of sown tropical pastures in northern Australia and currently the most prominent legumes are *Stylosanthes hamata* cv. Verano, *Stylosanthes scabra* cv. Seca, *Cassia rotundifolia* cv. Wynn, and *Aeschynomene americana* cv. Glenn (Hutchinson, 1992). Including the temperate and mediterranean zones, over 100 million hectares in Australia have been planted or become naturalised to legumes bringing vast new areas into potential arable production. Australian experience is the first and pre-eminent use of pasture legumes for extensive grasslands.

(ii) Pacific Islands. The islands of the South Pacific were originally vegetated with tropical rainforest but some 1500 years of human habitation (at least for Polynesia), has substantially modified the vegetation. Contemporary plant enumerations (e.g. Sykes, 1970) reveal a rich diversity of native, naturalized and introduced grassland flora attributed to accidental introductions associated with European contact from the 18th Century. Pasture types include natural grasslands, pastures under coconuts, and replacement pastures (Shelton et al., 1986). Extensive areas of natural grasslands occur in Papua New Guinea (5 M ha), Fiji (300,000 ha) and the Solomon Islands (10-15,000 ha) where successful pasture improvement has been achieved by; (i) oversowing *Stylosanthes* spp, (ii) phosphate fertilizer application to stimulate growth of native legumes, or (iii) introducing a grazing tolerant grass. Pasture development within coconut plantations is principally a "smallholder" operation. The common need is for a robust shade tolerant species to resist weed invasion. Complete replacement pastures for open grazing are used on more extensive "estate" operations. Shelton et al. (1986) suggest that the major factors still to be addressed are lack of indigenous expertise in pasture agronomy and low adoption of pasture technology.

(iii) Southern China. The first purposeful introduction of pasture plants to southern China appears to have been in the 1950's. The emphasis initially was on forage plants for "cut and carry" feeding systems. Elephant grass (*Pennisetum purpureum*) is the favoured forage on the basis of yield, drought tolerance, capacity to "over-winter", and ease of management. From about 1980, the focus changed to pasture species for grazing, and introductions have included some 300 species. Most success has been achieved with tropical and subtropical species from Australia. Species evaluation work has placed emphasis on yield, palatability, growth period and adaptation, with siratro. Verano stylo and setaria (*Setaria sphacelata*) showing wide application in tropical and subtropical environments. Collection and investigation of native species with grazing potential commenced from the same time and following preliminary assessments of yield, digestibility and adaptability, one grass (*Pennisetum polystachyon*) and one legume (*Alysicarpus vaginalis*) were selected for further evaluation. Future work on plant improvement in southern China will (i) place equal emphasis on introduced and native species, (ii) select species mixtures on the basis of yield, quality and persistence, (iii) select species for each locality and system of utilization, and (iv) place special emphasis on tolerance to cold, drought and predators (Hwang Miao Yang et al., 1986).

3) Pasture establishment

Pasture establishment addresses a variety of component activities including site and seedbed preparation, seed treatment and method of planting with all operations scheduled to achieve "timeliness" in relation to seasonal conditions (Jones and Jones, 1971; Cook, 1980). Timeliness is important to ensure a correspondence of favourable seasonal conditions with germination and early growth. Timeliness requires careful planning and a capacity to deliver maximum effort over a limited period.

(i) Site preparation. The presence of groundcover of indigenous species operates against the establishment of sown species through competition for nutrients, moisture and light. A reduction in the presence of groundcover by grazing, burning, cultivation or herbicide treatment (either singly or in strategic combination) improves the prospect of successful establishment of sown species. It is axiomatic that··· "the better the seedbed the better the establishment". However, with some pasture legumes where logistics or finance limit full seedbed preparation, establishment into a partially prepared seedbed will see sown species progressively increase in presence over two or three seasons to ultimately achieve a satisfactory plant density.

(ii) Seed preparation. Special seed treatment measures may need to be taken shortly before planting. Legume seed of certain species (e.g. *Stylosanthes* spp) that occur with a naturally high proportion of hard seed requires scarification by mechanical or heat treatment to crack the seed coat for improved germination. Legume varieties with a naturally low concentration of hard seed (e.g. *Macroptilium* spp) require no scarification. Legume seed can be inoculated with the correct strain of bacteria and lime pelleted for protection against (i) the acid conditions associated with simultaneous superphosphate application, and (ii) sunlight where seed is left exposed on the soil surface. Grass seed may need to be treated with insecticide for protection against insect theft.

(iii) Planting time. For successful establishment, soil moisture is required firstly to soften and promote germination, and secondly to sustain survival of seedlings. The most significant management decision to take to ensure favourable moisture conditions is judicious selection of the time of planting. Planting too early in advance of onset of the wet season risks a high incidence of seedling mortality associated with unseasonal early rains, followed by a return to dry conditions. Planting too late invites logistical difficulties of operating machinery on wet ground, exposes seedlings of sown species to severe competition from native species, and limits the opportunity for sown species to complete their phasal development through to ripe seed within the growing season. Clearly, there is an optimal planting time for each pasture type and locality that strikes a balance between these mitigating factors. Grazing should normally be avoided for a short period (one or two months) following planting to avoid damage to emerging seedlings, and then a moderate grazing pressure be imposed to contain vigorous growth of the most competitive sward component (usually grass) and regrowth of the native vegetation. In conjunction with pasture development, it may be important to implement a soil conservation program to rehabilitate degraded land, and as a precautionary measure against the threat of soil erosion accompanying pasture development and intensive grazing. An earthworks program of contour banks, drains and stockwater reservoirs, can be accompanied by strategic tree plantings to provide shelterbelts, shade, and water conservation.

4) **Fertilizer program.**

Native pasture in tropical and subtropical environments is notoriously low in both nitrogen and phosphorus status due to low levels of soil organic matter in these leaching environments. Soil deficiency may cause dietary deficiencies usually of energy, nitrogen and phosphorus for grazing animals. This is the focus of pasture improvement; to introduce legumes which improve both feed quantity and quality for grazing livestock, and to promote increased soil fertility through accumulation of soil organic matter.

The role of fertilizer in a pasture development program is essentially twofold; firstly to ameliorate soil nutrient deficiency and promote vigour of sown species, and secondly to increase the supply of essential nutrients to levels satisfactory for adequate growth and performance of grazing animals. Diagnosing soil nutrient deficiency and developing guidelines for a fertilizer program is a role for local adaptive research. This is pursued through a combination of soil analysis to specify gross soil nutrient status, nutrient omission pot (or plot) trials to diagnose nutrients that limit growth, and fertilizer rate trials to determine the quantity of fertilizer necessary for maximum pasture yield (Teitzel, 1978).

A fertilizer program has two distinct components, (i) an initial application to correct known deficiencies and facilitate pasture establishment, and (ii) maintenance applications in subsequent years to provide an adequate supply of nutrients for sustained pasture and animal production. If the magnitude of the pasture development project warrants it, and if resources are available, research may proceed to include fertilizer rate grazing studies to determine the fertilizer program that optimizes profitability (Rayment and Helyar, 1980). In the longer term, and following a number of years of successive fertilizer applications, research may be directed at determing the minimal fertilizer strategy that maintains a stable botanical community for sustainable animal production.

5) **Grazing management**

Grazing management is the procedure whereby the number and movements of cattle are strategically manipulated to provide effective utilization of pasture for maximum animal production, and at the same time appropriate protection of pasture plants is maintained against excessive defoliation to ensure persistence of sown species. There are two components of grazing management:

(1) Stocking rate … number of cattle per unit area

(2) Strategic grazing … movement of cattle between pasture areas.

For each pasture type there is an optimal system of grazing management. The correct stocking rate is generally the number of cattle per unit area that can be maintained year-round with minimal liveweight loss during the dry season. There is normally adequate pasture growth during the wet season to support a relatively greater stocking pressure but a portion of this growth must be reserved for utilization in the dry season when pasture is dormant. For example, for one region in the Australian dry tropics, a stocking rate of about 0.75 cow equivalents per hectare on improved pasture (*Stylosanthes* spp) is considered to be a relatively safe level at which to operate (Gillard and Winter, 1984). (Accounting for the difference in body size between improved cattle genotypes and native Asian cattle this corresponds to 1.25 native cow equivalents per hectare). It is necessary for each locality to undertake stocking rate experiments to derive appropriate stocking rate statistics for resident pastures.

Traditional grazing systems employ one version or other of night time shedding coupled with shepherding animals during daylight hours around preferred areas of native pasture within close walking distance. This practice invariably promotes severe overgrazing of land close to the village, under-utilization of outlying grazing areas, and malnutrition of cattle. With the introduction of improved pastures, it is important to adopt new grazing management practices that provide efficient utilization of the new feed resource. A management system must also account for the needs of pasture plants for protection against excessive defoliation at critical times of phasal development that are important for regeneration. These critical stages of maturity might include, for example; the early vegetative stage of perennial grasses (accumulation of nutrient reserves), flowering to pod shatter stage of vine legumes (seedling recruitment), and the regrowth vegetative stage of perennating legumes (stolon extension). Overgrazing or undergrazing can promote botanical instability and ultimate demise of sown species. Much research has been undertaken in Australia to determine the correct stocking rate and system of strategic grazing for the principal pasture types. It is necessary for each locality to undertake grazing management experiments to account for local circumstances.

To illustrate an example of strategic grazing, it is instructive to consider a system successfully employed to provide integrated grazing of siratro/setaria (*Macroptilium atropurpureum/Setaria sphacelata*) and stylo/buffel (*Stylosanthes hamata/Cenchrus ciliaris*) pastures that are prominent in dry tropical environments (Ayres, 1983b). Siratro/setaria pasture can be considered as primarily available for utilization during the wet season, while stylo/buffel has characteristics that are useful for dry season grazing. The natural complementary relationship of these two pasture types can be exploited in a pasture development program by appropriate comparable areas of each to provide an integrated grazing system. Using a grazing management strategy termed variable continuous grazing (Roberts, 1979), both pastures within a development unit are continuously grazed, but a portion of the herd is progressively moved between pasture types according to the feed supply and the specific species requirements for defoliation or spelling, viz.:

(1) Spring ··· continuous grazing of both pastures but relatively greater grazing pressure on stylo/buffel to reduce grass competition against emerging stylo seedlings

(2) Summer/autumn ··· continuous grazing of both pastures but relatively greater grazing pressure on siratro/setaria to contain vigorous grass competition

(3) Winter ··· continuous grazing of both pastures but grazing pressure reduced on siratro/setaria to promote flowering and seeding of siratro.

A further smoothing of this integration can be achieved by establishing leucaena at approximately 5 percent per unit area to provide high quality browse forage for utilization in spring in the event of a late commencement to the wet season. This integration constitutes a "robust" pasture system.

Pasture improvement imposes a commitment into the future to maintain adequate resources of fertilizer and management to ensure persistence and productivity from sown species into the long-term. Experience has consistently shown that if correct management practices are not maintained, improved pasture will lose vigour, become botanically unstable, and eventually revert to native vegetation.

Grazing production from improved pastures

Tropical and subtropical environments are characterised by summer rainfall providing rapid pasture growth over summer but low nutritive value through the dry season. This seasonal pattern, together with low soil fertility, can severely limit cattle production in tropical environments. The main limitation of tropical pastures for cattle is a deficiency of green feed in the dry season and low nutritive value during most of the growing season. Cattle grazing tropical pastures achieve only about 15-20 percent of their potential for liveweight gain (Mannetje, 1982). Low reproductive rate is due to undernutrition during the long dry season leading to poor growth to puberty, and variable intervals between pregnancies, particularly with heifers (Sutherland, 1959; Franklin, 1959). Studies on the reproductive rate of beef cattle in northern Australia show that conception rate varies between 45-90 percent, embryo loss between 5-50 percent (Donaldson et al., 1967; Lamond, 1969; Holroyd et al., 1979), and branding rate averages 70 percent, or less.

This low performance occurs because management of beef cattle in northern Australia is mainly *extensive* and breeding herds predominantly graze native pastures. Cattle are normally mustered only once or twice yearly, bulls run in the herd without restriction for year-round calving, and weaning is implemented only where practicable. Lactation stress associated with calves on cows over the dry season, coupled with poor dry season nutrition and periodic droughts result in high mortality of breeders; typically 15 percent. Annual turnoff rarely exceeds 10 percent of total herd numbers (Daly, 1971). The major factors affecting reproductive performance are the proportion of lactating cows in the herd, the proportion of first calf cows, the condition of calving cows, and the over riding influence of poor nutrition. Conditions in Asian and Pacific countries can be substantially different. Obviously, management of livestock can be intensive and there is potential through (i) pasture improvement, (ii) strategic feed supplementation, and (iii) intensive husbandry to achieve high levels of productivity.

1) Animal production from improved pastures

The contribution of legume based pastures to increased animal production rests on the following foundations:

(1) Where soil mineral status is adequate, the presence of a sown legume contributes to soil fertility, particularly soil nitrogen status through the nitrogen accretion properties of the rhizobium - root nodule complex

(2) Increase in soil nitrogen status supports the adaptation of high yielding introduced grasses in a "replacement" pasture system, or promotes the ingress of more vigorous native grasses in "oversown" pasture

(3) A mixed legume/grass sward provides a diet conferred with the superior nutritive value characteristics of legumes, particularly enrichment in protein status.

Experience in northern Australia provides evidence of a dramatic increase in cattle production from improved pastures, through increases in carrying capacity, and in liveweight gain, more rapid "turn-off" of fattened stock, and an increase in reproductive rate.

The first grazing investigation of legume/grass pasture in northern Australia commenced at Lawes, Queensland in 1946 (Christian and Shaw, 1952), where it was shown that the inclusion of a small component of lucerne with rhodes grass (*Chloris gayana*) significantly increased cattle production. This effect was broadly attributed to a stimulus to both yield and quality of the grass, combined with a direct nutritional effect from lucerne in the diet. Another early grazing study, undertaken at Rodds Bay, Queensland in 1955 (Shaw, 1961) demonstrated a three-fold increase in carrying capacity and a five-fold increase in liveweight gain from Townsville stylo (plus phosphate fertilizer) oversown into speargrass (*Heteropogon contortus*). The cause of this effect was investigated in greater detail subsequently, and it was concluded that there was a general correspondence between liveweight gain and legume yield, but that phosphate fertilizer also increased the forage concentration of phosphorus and nitrogen in both legume and grass sward components to overcome limiting deficiencies of these nutrients (Thornton and Minson, 1973; Shaw, 1978).

Following numerous grazing studies in the Australian tropics and subtropics, there is now general agreement from both the scientific literature and practical experience, that pasture improvement based on the introduction of legumes, consistently promotes a substantial increase in cattle production. A survey of grazing studies on tropical and subtropical grasslands suggests that pasture improvement with legumes and phosphate fertilizer increase carrying capacity two to six-fold and overall cattle production up to six fold (Stobbs, 1975; Mannetje, 1978; Mannetje et al., 1980). The *actual* increase in cattle production from a pasture development program will, however, depend on numerous factors set by environment and management constraints. Based on observation and experience, the following is proposed as a framework of realistic expectations:

(1) "Partial replacement" pasture (introduced legume/native grass) promotes a gradual two-fold build-up in carrying capacity for an ultimate three-fold increase in cattle production

(2) "Full replacement" pasture (introduced legume/introduced grass) provides a highly productive pasture from the season of establishment for a three-fold increase in carrying capacity and a five-fold increase in cattle production

(3) An "integrated" pasture system combining a minor area of sown pasture on better quality accessible and arable soils, juxtaposed with adjacent "run-off" native pasture, will support a 50 percent increase in carrying capacity and 75-100 percent increase in cattle production.

The upper level of cattle production from legume based pasture in northern Australia is about 500 kg liveweight gain ha^{-1} per annum (table 2). The potential limit of production (as defined by nitrogen fertilized dryland pasture) is about 1,000 kg liveweight gain ha^{-1} per annum (Bryan and Evans, 1971; Mears and Humphreys, 1974; Harding and Grof, 1978). Mannetje (1982) reported some exceptional values of up to 2,760 kg liveweight gain ha^{-1} per annum from irrigated fertilized grass in the Australian wet tropics.

2) Significance of pasture legumes for diet quality

Early exponents of legume based pastures advocated that pasture utilization and the efficiency of conversion of pasture to animal product progressively increase corresponding to greater legume presence in pasture, and that maximum utilization would be achieved from pure legume swards (Hutton, 1968). Many grazing experiments have been undertaken to explore the nature of the relationship of pasture improvement and animal production, but the plant/animal interface is complex and only a few studies provide strong evidence for a "cause and effect" relationship between the level of legume presence and grazing production (table 3).

Empiric relationships of association have been reported for certain pasture conditions; (i) where the indigenous pasture is very low in nutritive value (Evans, 1970; Bryan, 1973; Cohen et al., 1984), and (ii) in pasture environments with a discrete and prolonged dry season (Norman, 1970). In both situations, intake is restricted by nitrogen deficiency. The addition of legume serves initially (i.e. at 10-20 percent legume presence) as a protein supplement to overcome nitrogen deficiency and stimulate increased intake of grass (Minson, 1971). At higher levels, legume substitutes for grass and confers an improvement in digestibility of the mixed diet (Minson and Milford, 1967). A relationship for other than low quality or dry season pasture has not been established. For example, Eng et al. (1978) found no relationship for a (centro/stylo/peuro) legume-guinea grass pasture and suggested that the predominant "legume effect" for better quality pastures comes principally from the contribution of improved nitrogen supply to the companion grass. Increased cattle production from legume based pasture has been variously ascribed by other workers to the superior nutritive value of legumes, or alternatively to an indirect effect, sometimes proven, sometimes surmised, viz.:

(i) Stimulus to growth (Lowe et al., 1977) or quality (Thornton and Minson, 1973) of indigenous pasture species due to improved nitrogen supply from the legume-rhizobial complex, fertilizer applied at establishment, or soil nutrients mineralized through cultivation

(ii) Dietary supplementation from fertilizer minerals (Shaw and Mannetje, 1970)

(iii) Increased yield potential (Shaw and Mannetje, 1970) or extended growing season of the introduced legume (Hogg, 1965).

Shaw and Mannetje (1970) hypothesised that legume presence might influence soil nutrient cycling processes and stimulate indigenous species to make greater use of soil water and nitrogen. Increased cattle production may also accompany improved grazing management and livestock husbandry that normally are associated with a pasture improvement program.

To summarize, results from Australian studies

TABLE 2. SUMMARY OF CATTLE LIVEWEIGHT GAIN (KG. MAXIMUM VALUES) AND STOCKING RATES FROM IMPROVED LEGUME BASED PASTURES IN NORTHERN AUSTRALIA

Location	Rainfall (mm)	Pasture species	Stocking rate (head ha^{-1})	Liveweight gain (kg ha^{-1} pa)	Source
Grafton (29 ° S)	983	*Axonopus affinis /T. repens*	2.5	333	Cohen et al. (1984)
Wollongbar (28 ° S)	1,678	*Pennisetum clandestinum /T. repens*	3.3	452	Mears & Humphreys (1974)
Beerwah (27 ° S)	1,650	*Digitaria decumbens /T. repens*	2.8	479	Jones (1984)
Beerwah (27 ° S)	1,650	*Paspalum commersonii /Desmodium intortum, T. repens*	2.4-3.6	265	Bryan (1968)
Esk (27 ° S)	957	Native grass /*Macroptilium atropurpureum*	1.1	135	Lowe et al. (1977)
Maryborough (25 ° S)	1,016	*Heteropogon contortus /M. atropurpureum*	1.25	116	Mannetje (1972)
Rodds Bay (24 ° S)	856	*H. contortus /Stylosanthes humilis*	0.4-1.6	129	Shaw (1978)
Central Qld (23 ° S)	686	*Panicum maximum /M. atropurpureum*	0.8	109	Hall (1970)
Innisfail (17 ° S)	3,250	*Panicum maximum /Centrosema pubescens*	2.7	586	Mellor & Round (1974)
S. Johnstone (17 ° S)	3,225	*P. maximum /C. pubescens*	1.7	456	Grof & Harding (1970)

are consistent with theoretical expectations in demonstrating significant increases in animal production from legume based pasture. However, the "legume effect" is a complex of the direct effect of the legume enriching diet quality, and a variety of indirect effects some of which can be attributed to other legume attributes, but some effects are artifacts of pasture establishment.

3) Supplementary feeding

The diet of cattle grazing native pasture in the dry season is typically deficient in nitrogen,

TABLE 3. SUMMARY OF CATTLE LIVEWEIGHT GAIN (KG. LWG HA^{-1} PER ANNUM) FROM GRASS PASTURE COMPARED WITH LEGUME / GRASS PASTURE IN AUSTRALIA.

Location	Rainfall (mm)	Pasture species	Stocking rate (head ha^{-1})	Liveweight gain Grass	Liveweight gain Grass/legume	Source
Lawes (27 °S)	740	*Chloris gayana* /*M. sativa*	2.0	90	179	Christian & Shaw (1952)
Beewah (27 °S)	1,650	*D. decumbens* /*T. repens*	2.5		290i* 336ii* 545iii*	Evans (1970)
Rodds Bay (24 °S)	813	*H. contortus* /*S. humilis*	0.6 0.75 0.75	24i** —	— 90ii** 144iii**	Shaw & Mannetje (1970)
S. Johnstone (17 ° S)	3,225	*P. maximum* /*C. pubescens*	4.0	334	456	Grof & Harding (1970)

* *(i): 13 percent legume, (ii): 20 percent legume, (iii): 35 percent legume.*
** (i) and (ii): nil phosphate fertiliser, (iii): plus phosphate fertiliser.

digestible energy, and possibly specific minerals (e.g. phosporus, sulphur) depending on inherent soil fertility (Hendricksen et al., 1986). Nitrogen is the nutrient in shortest supply (Hennessy, 1980), and nitrogen supplements are used successfully in northern Australia to reduce dry season liveweight loss, reduce mortality of breeding cows, and increase conception rate (Holroyd et al., 1977). Suitable supplement sources are (i) out-of-season green feed (e.g. irrigated pasture), (ii) legume forage (e.g. leucaena) or hay, (iii) protein supplements, and (iv) urea/molasses.

In certain circumstances, cattle may also show a positive response to supplementation with specific mineral supplements. For example, native pasture may be marginal in phosphorus status during the wet season and deficient during the dry season (Little, 1970). A response to phosphorus supplementation, however, is contingent upon adequate levels of dietary protein; phosphorus supplementation is only recommended in the Australian dry tropics for young lactating cows grazing native pastures during the wet season or for cattle grazing stylo pasture (Holroyd et al., 1977). Supplementation with sulphur can improve the intake of native grass and stylo legume, and is recommended for use in conjunction with urea or legume nitrogen (Playne, 1969). The principal native grass (*Heteropogon contortus*) and improved legume (*Stylosanthes* spp) of the dry tropics provide diets low in sodium for grazing cattle that may decline to deficiency status on low sodium soils during the dry season (Playne, 1970). Trace element levels can be low in pasture growing on tropical sands; deficiency levels of copper and cobalt occur with improved panic/stylo pasture and a dramatic response in cattle growth to cobalt administration is known to occur (Winter et al., 1977).

4) Increased animal production from improved husbandry

Gains in cattle production may also follow the introduction of improved management and husbandry practices. For example, the application of improved management and feeding of native Malaysian cattle resulted in an increase in mature liveweight from 250 kg to 275 kg, an increase in slaughter weight from 120 to 200 kg, an increase in calving rate from 60 percent to 80 percent and a reduction in age at first calving from 44 months to 27 months (Maule, 1982). Similar results are reported by Michalk et al. (1986) for the native cattle of southern China.

A 50 percent increase in individual cattle performance can be expected to follow the introduction of a rudimentary improved husbandry program that includes restructuring into classical cow/weaner/steer groups, castration, weaning, restricted joining, and open grazing of improved pasture (Ayres, 1983b). Further gains of some 15-20 percent can be expected from the progressive introduction of more advanced levels of husbandry that integrate new technologies of supplementary feeding, disease and parasite control, and livestock breeding into routine management practice.

Conclusions

Successful livestock improvement through pasture development requires effective management control from initial site preparation and planting of introduced species through to grazing management of established pastures. To ensure long term stability and persistence of improved pastures, grazing management must be carefully regulated. Overgrazing or undergrazing will precipitate botanical changes and ultimate reversion to native vegetation. Loss of management control over land may also lead to intrusive activities like intermittent burning and shifting cultivation that in turn constitute a threat to the persistence of introduced species. Likewise, success with animal husbandry innovations demands effective control of the paddock movements of livestock, segregation of the herd into functional groups, isolation of bulls to facilitate restricted seasonal mating, and protection of the herd from theft. Without control over land use, livestock improvement programs based on free ranging of improved pasture are unlikely to be successful.

These pre-requisites for successful implementation of pasture and grazing technology clearly imply that land designated for pasture development be secure from intrusions and other adverse influences. Experience with pasture development across Asian and Pacific cultures shows that designation of an area for agricultural development by authorities does not necessarily guarantee protection from actions of local people if they are not convinced that the long term benefits from modernisation exceed the short-term benefits from traditional use. Indigenous people with low living standards and risky production possibilities may not be able to afford the luxury of long-term planning for a better future where it requires sacrificing present possibilities for food production or extra income. Consequently, pasture development may need to be located initially in sparsely populated regions or on well established and clearly designated sites not subject to threatening influences.

Of the difficulties confronting livestock improvement through pasture development, three broad challenges are identifiable; technical, logistical and socio-cultural. The *technical* challenge of defining the grassland environment and adapting known technology to local conditions can be successfully addressed by local technicians supported by the reservoir of appropriate international experience. Two considerations are of axiomatic importance:

(1) The primary focus of a livestock improvement program should initially be pasture development. The time honoured maxim "feeding before breeding" is predicated on two verifiable principles; (i) the relative performance of different livestock genotypes is influenced by environmental conditions (i.e. the phenomenon of genotype/environment interaction), and (ii) the feed regime is a component of the grazing animal's environment. Accordingly, it is essential to establish and consolidate feed and management conditions *before* embarking on new livestock breeding technologies.

(2) Local adaptive research should be undertaken in each significantly different agro-geographic locality to develop technologies and practices that account for local influences. Indigenous agencies are notorious for seeking short-cut solutions by locating pasture projects on the poorest and most adverse sites on the fallacious basis that "whatever might be achieved here can be duplicated manyfold elsewhere".

Logistical difficulties that include establishment of infrastructure to provide continuity of support services to development initiatives are an obvious responsibility of indigenous support organizations. Prior assessment should determine the organizational structures and lines of flow of responsibility and communication to ensure timely supply of resources and efficient linkages with existing local expertise.

Socio-cultural factors are fundamentally pervasive. Conflict over land use may have foundation in immutable historical precedents (e.g. traditional rights), or previous government policies, and be exacerbated by new policies promoting modernisation. Without a judicial system of land tenure where the philosophic orientation is to land use rather than land ownership, problems can be acutely complex. Conflicts may also extend to other primary resources like irrigation water, fertiliser, fuel, and skilled labour as operations intensify. Moreover, the indigenous perspective of the merits of a new agricultural activity may not necessarily be solely shaped by classical economic or utility analysis but rather in terms of some measure of social benefit.

Pasture development may constitute a profound change in land use and life style, so prior assessment of social organization and socio-cultural constrains should be *sine qua non*.

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Literature Cited

Archer, K. A. and A. Gresser. 1979. White clover in New South Wales. NSW Department of Agriculture Plant Industry Bulletin.

Ayres, J. F. 1983a. The feedstuff information requirements of countries with traditional animal husbandry systems. In: Feed Information and Animal Production (Eds. G. E. Robards and R. G. Packham). CAB.

Ayres, J. F. 1983b. Gaopoling Model Cattle Farm Project: Progress Report 1981-82. Overseas Projects Section, NSW Agriculture.

Ayres, J. F. 1985a. North Guangdong Model Cattle Farm: Feasibility Study Report. Overseas Projects Section, NSW Agriculture.

Ayres, J. F. 1985b. Rehabilitation of Beef Cattle Pastures on Niue Island, South Pacific. Overseas Project Section, NSW Agriculture.

Bryan, W. W. 1968. Grazing trials on the Wallum of South-Eastern Queensland. I. A comparison of four pastures. Australian Journal of Experimental Agriculture and Animal Husbandry. 8:512-520.

Bryan, W. W. and T. R. Evans. 1971. A comparison of beef production from nitrogen fertilized pangola grass/legume pasture. Tropical Grasslands. 5(2): 89-98.

Bryan, W. W. 1973. Tropical and subtropical forests and heaths. In: Australian Grasslands (Ed. R. Milton Moore). p. 101-111, ANU Press.

Buggie, G. J. 1980. The economics of developing tall tropical legume based pastures for beef cattle. Tropical Grasslands 14(2):127.

Chen Wen, Z. H. Liu, M. Y. Yang, G. E. Eagleton, R. L. Lisle and B. K. Mitchelhill. 1992. The role of lucerne in developing the agriculture systems of eastern Gansu, China. Proceedings of the 6th Australian Agronomy Conference. pp. 422-424.

Christian, C. S. and N. H. Shaw. 1952. A study of two strains of rhodes grass (*Chloris gayana K.*) and of lucerne (*Medicago sativa L.*) as components of a mixed pasture at Lawes in south-east Queensland. Australian Journal of Agricultural Research. 3:277-299.

Cocks, P. S., M. J. Mathison and E. J. Crawford. 1978. From wild plants to pasture cultivars: annual medics and subterranean clover in southern Australia. In: Advances in Legume Science, Proceedings of International Legume Conference, Kew, United Kingdom.

Cohen, R. D. H., E. J. Havilah and G. H. O'Neil. 1984. Superphosphate requirements for maintenance of cattle production from grass - clover pastures in a subtropical environment. Australian Journal of Experimental Agriculture and Animal Husbandry. 24:189-199.

Colman, R. L. 1971. Quantity of pasture and forage crops for dairy production in the tropical regions of Australia. Tropical Grasslands. 5:181-194.

Cook, S. J. 1980. Establishing pasture species in existing swards: a review. Tropical Grasslands. 14(3):181-187.

Daly, J. J. 1971. Beef breeder study in the north-west. Queensland Agricultural Journal. 97:93-100.

Davidson, B. R. 1981. Agriculture and the economy. In: A Manual of Australian Agriculture (Ed. by R.C. Reid). pp. 1-21. William Heinemann Australia, Melbourne.

Donald, C. M. 1967. Innovation in Agriculture. In: Agriculture in the Australian Economy (Ed. by D. B. Williams). Sydney University Press.

Donaldson, L. E., J. B. Ritson and D. B. Copeman. 1967. The reproductive efficiency of several north Queensland beef herds. Australian Veterinary Journal. 43:1-6.

Eng, P. K., L. T. Mannetje and C. P. Chen. 1978. Effects of phosphorus and stocking rate on pasture and animal production from a guinea/grass-legume pasture in Johore, Malaysia. Tropical Grasslands. 2(3):198-207.

Evans, T. R. 1970. Some factors affecting beef production from subtropical pastures in the coastal lowlands of South-East Queensland. Proceedings of the 11th International Grasslands Congress. pp. 803-807.

Eyles, A. G., D. G. Cameron and J. B. Hacker. 1985a. Pasture Research in Northern Australia - its history, achievements and future emphasis. pp. 7-36. CSIRO Division of Tropical Crops and Pastures, Brisbane.

Fyles, A. G., D. G. Cameron and J. B. Hacker 1985b. Pasture Research in Northern Australia - its history, achievements and future emphasis. pp 121-139. CSIRO Division of Tropical Crops and Pastures, Brisbane.

Faletau, Meleseini and J B Hardaker. 1988. Regional development; infrastructure and institutions. In: Smallholder Agricultural Development in Tonga, Proceedings of a Workshop held at the Institute for Rural Development, University of the South Pacific, Nuku'alofa, Tonga, 12-13 May 1988. ACIAR Proceedings. No. 24, 50 p.

Franklin, M C. 1959 Factors affecting the performance of beef cattle on unimproved pastures in Queensland Australian Veterinary Journal 35:135-140.

Gentilli, J. 1971. Climates of Australia and New Zealand, World Survey of Climatology Vol. 13. Elsevier Publishing Company, Amsterdam.

Gillard, P and W. H. Winter. 1984 Animal production from *Stylosanthes* based pastures in Australia. In: The Biology and Agronomy of *Stylosanthes* (Ed. by H. M. Stace and L. A. Edye). Academic Press, Australia.

Grof, B. and W. A. T. Harding. 1970. Dry matter yields and animal production of guinea grass (*Panicum maximum*) on the humid tropical coast of North Queensland Tropical Grasslands. 4(1): 85-95.

Hall, R. L. 1970. Pasture development in the Spear Grass Region at Westwood in the Fitzroy Basin. Tropical Grasslands. 4(1):77-84.

Harding, W. A. T. and B. Grof. 1978 Effect of fertilizer nitrogen on yield, nitrogen content and animal productivity of *Brachiaria decumbens* cv Basilisk on the wet tropical coast of North Queensland. Queensland Journal of Agriculture and Animal Science. 35(1):11-21.

Hendricksen, R. E., R W. McLean and R. W. Dicker. 1986. The role of supplements and diet selection in beef production and management of tropical pastures in Australia. Proceedings of the Third Australian Conference on Tropical Pastures, Rockhampton. 8-12 July, 1985.

Hennessy, D. W. 1980. Protein nutrition of ruminants in tropical areas of Australia. Tropical Grasslands. 14(3):260-265.

Hogg, P. G. 1965. Effect of legumes and fertilizers on yield of cultivated *Cynodon* (Coastal Bermudagrass) pastures in Southern U.S.A. Proceedings of the 9th International Grassland Congress. pp. 1099-1101

Holroyd, R. G , Anlan, P. J. and P. K. O'Rourke. 1977. Effect of pasture type and supplementary feeding on the reproductive performance of cattle in the dry tropics of north Queensland. Australian Journal of Experimental Agriculture and Animal Husbandry. 17:197-206.

Holroyd, R. G., B. A. Arthur and B. G. Mayer. 1979. Reproductive performance of beef cattle in north -western Queensland. Australian Veterinary Journal 55:257 262.

Hutchinson, K. J. 1992. The grazing resource. Proceedings of the 6th Australian Agronomy Conference pp 54-60.

Hutton, E. M. 1968. Australia's pasture legumes. Journal of the Australian Institute of Agricultural Science. 34:203-218.

Hutton, E. M. 1974. Tropical pastures and beef production. World Animal Review. 12:1-7.

Hwang Miao Yang, Wun Lan Xiang and Zhang Ching Zhe. 1986. The main varieties of forages and their evaluation in Southern China. In: Forages in Southeast Asian and South Pacific Agriculture: proceedings of an International Workshop held at Cisarua, Indonesia, 19-23 August 1985 (Ed. by G J Blair, D. A Ivory and T. R. Evans). ACIAR Proceedings Series No. 12. pp. 76-79.

Ivory, D A. 1986. Performance of germplasm in new environments. In: Forages in Southeast Asian and South Pacific Agriculture: proceedings of an international workshop held at Cisarua, Indonesia, 19-23 August 1985 (Ed. by G. A. Blair, D. A. Ivory and T. L. Evans) ACIAR Proceedings Series. No. 12, pp. 61-68.

Jones, R. J. and R. M. Jones. 1971. Agronomic factors in pasture and forage crops production in tropical Australia. Tropical Grasslands. 5(3):229-224.

Jones, R. J. 1976. Yield potential of tropical pasture legumes. Proceedings of a Workshop on Exploiting the Legume-Rhizobium Symbiosis in Tropical Agriculture, Hawaii, 23-28 August, 1976.

Jones, R. M. 1984. White clover (*Trifolium repens*) in subtropical south-east Queensland. III Increasing clover and animal production by use of lime and flexible stocking rates. Tropical Grasslands. 18(4): 186-194.

Kendrew, W. G 1961. The Climates of the Continents. Oxford University Press.

Lamond, D. R. 1969. Sources of variation in reproductive performance in selected herds of beef cattle in north-eastern Australia Australian Veterinary Journal. 45:50-58.

Leeper, G W. 1970. Soils. In: The Australian Environment (Ed. by C. W. Leeper). pp. 21-31. Melbourne University Press, Victoria.

Little, D. A. 1970. Factors of importance in the phosphorus nutrition of beef cattle in northern Australia. Australian Veterinary Journal. 46:241-248.

Lowe, K. F., G. F. Filet, M. A. Burns and T. M Bowdler. 1977. Effect of sod-seeded siratro on beef production and botanical composition of native pasture in South-Eastern Queensland. Tropical Grasslands. 11(3):223-230.

Macfarlane, D. and M. Shelton 1986. Pastures in Vanuatu. ACIAR Technical Report Series. No. 2, 32 p.

Mannetje, L. 't. 1972. The role of native pastures oversown with an introduced legume for beef production in the Brisbane Valley Tropical Grasslands. 6(3):244-246.

Mannetje, L. 't. 1978. The role of improved pastures for beef production in the tropics. Tropical Grasslands. 12(1):1-9.

Mannetje, L. 't. 1982. Problems of animal production from tropical pastures. In: Nutritional Limits to Animal Production from Pastures (Ed. by J. B. Hacker), CAB: United Kingdom.

Mannetje, L. 't., K. F. O'Conner and R. L. Burt. 1980. The use and adaptation of pasture and fodder legumes. In: Advances in Legume Science (Ed. by R. J. Summerfield and A. H. Bunting), Kew, United Kingdom.

Maule, J. P. 1982. The Kedah Kelantan cattle of Malaysia. World Animal Review. 41:34-39.

Mears, P. T. and L. R. Humphreys. 1974. Nitrogen response to stocking rate of *Pennisetum clandestinum* pasture. II. Cattle growth. Journal of Agricultural Science, Cambridge 83:469-478.

Mears, P. T. and I. J. Partridge. 1985. Commercial usage of improved pastures in the Australia subtropics. Proceedings of the Third Australian Conference on Tropical Pastures (Tropical Grassland Society of Australia Occasional Publication No. 3) pp. 119-127.

Mellor, W. and P. J. Round. 1974. Performance of beef steers in the wet tropics of Queensland. Queensland Journal of Agriculture and Animal Science. 30 : 53-56.

Menz, K. M. 1980. Smallholder Agricultural Development in Tonga: Proceedings of a Workshop held at the Institute for Rural Development, University of the South Pacific, Nuku'alofa, Tonga 12-13 May 1988. ACIAR Proceedings. No. 24, 50 p.

Michalk, D. L., Fu Nan Ping, P. T. Mears and H. Zhen Zheng. 1984. Improvement of wasteland in tropical south China. Proceedings of the Second International Rangeland Congress, Adelaide, Australia.

Michalk, D. L., J. F. Ayres, Fu Nan Ping and Zhu Chin Min. 1986. Range improvement in tropical China: Gaopoling Model Cattle Farm. Proceedings of the 15th International Grasslands Congress, Kyoto, Japan.

Minson, D. J. and R. Milford. 1967. The voluntary intake and digestibility of diets containing different proportions of legume and mature Pangola grass (*Digitaria decumbens*). Australian Journal of Experimental Agriculture and Animal Husbandry. 7: 546-551.

Minson, D. J. 1971. The nutritive value of tropical pasture. Journal of the Australian Institute of Agricultural Science. 37:155-263.

Nalson, J. S. and J. F. Ayres. 1984. Development projects and the production responsibility system in China: a case study. Australian Journal of Chinese Affairs. 11:131-145.

Norman, M. T. 1970. Relationships between liveweight gain of grazing beef steers and availability of Townsville lucerne. Proceedings of the XI International Grassland Congress, Surfers Paradise, Australia.

O'Brien, A. D. 1970. Evaluating white clover varieties for the Clarence River beef country. Tropical Grasslands. 4(1):63-69.

O'Brien, A. D. and R. D. H. Cohen. 1972. Naturalized white clover on the North Coast. New South Wales Department of Agriculture Plant Industry Bulletin. p. 445.

Osborne, H. G. 1960. The investigation of infertility syndromes on beef herds. Australian Veterinary Journal. 36:164-171.

Ostrowski, H. 1972. White clover (*Trifolium repens*) in sub-tropical Australia - a review. Tropical Grasslands. 6(2):97-106.

Playne, M. J. 1969. Effects of sodium sulphate and gluten supplements on the intake and digestibility of a mixture of spear grass and Townsville lucerne hay by sheep. Australian Journal of Experimental Agriculture and Animal Husbandry. 9:393-399.

Playne, M. J. 1970. The sodium concentration in some tropical pasture species with reference to animal requirements. Australian Journal of Experimental Agriculture and Animal Husbandry. 10:32-35.

Rayment, G. E. and K. R. Helyar. 1980. Estimation of maintenance fertilizer needs. Tropical Grasslands. 14(3):210-217.

Reynolds, S. G. 1981. Grazing trials under coconuts in Western Samoa. Tropical Grasslands.15:3-10.

Roberts, C. L. 1979. Some common causes of failure of tropical legume/grass pastures on commercial farms and suggested remedies. In: Pasture Production in Acid Soils of the Tropics (Ed. by P. A. Sanchez and L. E. Tergas), CIAT, Cali, Colombia.

Shaw, N. H. 1961. Increased beef production from Townsville lucerne (*Stylosanthes sundaica* Taub.) in the speargrass pastures of central coastal Queensland. Australian Journal of Experimental Agriculture and Animal Husbandry. 1:73-80.

Shaw, N. H. 1978. Superphosphate and stocking rate effects on a native pasture oversown with *Stylosanthes humilis* in central coastal Queensland. 2. Animal production. Australian Journal of Experimental Agriculture and Animal Husbandry. 18: 800-807.

Shaw, N. H. and L. 't. Mannetje. 1970. Studies on a spear grass pasture in Central Coastal Queensland - the effect of fertilizer, stocking rate and oversowing with *Stylosanothes humilis* on beef production and botanical composition. Tropical Grasslands. 4 (1):43-56.

Shaw, N. H. and M. J. T. Norman. 1970. Tropical and subtropical woodlands and grasses. In: Australian Grasslands [Ed. by R. L. Milton Moore], pp. Australian National University Press, Canberra.

Shelton, H. M., M. Raurela and G. I. Tupper. 1986. Forages in the South Pacific and Papua New Guinea. In: Forages in Southeast Asian and South Pacific Agriculture - proceedings of an international workshop held at Cisarua, Indonesia, 19-23 August, 1985, (Ed. by G. J. Blair, D. A. Ivory and T. R. Evans). ACIAR Proceedings Series. No. 12, pp. 89-95.

Stapledon, R. G. and W. Davies. 1941. Ley Farming.

Faber and Faber; London.

Steel, R. J. H., M. A. Smith and P. C. Whiteman. 1980. A Pasture Handbook for the Solomon Islands. Ministry of Agriculture and Lands, Honiara.

Stobbs, T. H. 1965. Beef production from Uganda pastures containing *Stylosanthes gracilis* and *Centrosema pubescens*. Proceedings of the 9th International Grasslands Congress, Sao Paulo, Brazil.

Stobbs, T. H. 1975. Beef production from improved pastures in the tropics. World Review of Animal Production 11(2)58-65.

Sutherland, D. N. 1959. Factors affecting the performance of beef cattle on unimproved pastures in Queensland. Australian Veterinary Journal. 35: 129-134.

Sykes, W. R. 1970. Contributions to the flora of Niue. New Zealand Department of Scientific and Industrial Research, Bulletin 200.

Teitzel, J. K. 1978. Formulation of pasture fertilizer programs for the wet tropical coast of Australia. In: Pasture Production in Acid soils of the Tropics (Ed. by P. A. Sanchez and L. E. Tergas), CIAT, Cali, Colombia.

Thornton, R. F. and D. J. Minson. 1973. Effects of soils, fertilizers and stocking rates on pasture and beef production on the Wallum of South-Eastern Queensland. 3. Relation of liveweight changes to chemical composition of blood and pasture. Australian Journal of Experimental Agriculture and Animal Husbandry. 13:537-543.

Tribe, D. E. 1989. A case history of agricultural research and development. Agricultural Science. 2(4): 14-21.

Vernon, D. 1984. Evaluating pastures for beef production. Proceedings of a field day at Fineflower in the Upper Clarence Valley, April 1984. New South Wales Department of Agriculture Agdex 420/820.

Williams, O. B. 1973. The environment. In: The Pastoral Industries of Australia, Practice and Technology of sheep and Cattle Production. (Ed. G. Alexander and O. B. Williams) pp. 3-40. Sydney University Press.

Williams, R. J. 1990. In. ACIAR Working Paper No. 32. Forage Germplasm Storage, Distribution, Evaluation and Multiplication. Papers presented at an AIDAB sponsored meeting August 13-18, 1989, Brisbane and North Queensland, Australia.

Winter, W. H., B. D. Siebert and R. E. Kuchel. 1977. Cobalt deficiency of cattle grazing improved pastures in northern Cape York Peninsula. Australian Journal of Experimental Agriculture and Animal Husbandry. 17:10-15.