AUSTRALIA'S PASTURE LEGUMES

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At the turn of the century William Farrer, Australia's pioneer plant breeder, made an outstanding contribution to our prosperity with the release of the wheat variety Federation which put the then struggling wheat industry on a firm basis. This so inspired a succession of wheat breeders and experimentalists that this industry has forged ahead, and last year had a gross value of $447 million with export earnings of $337 million. Our pastoral industries have also had a remarkable development due to the efforts over the years of landholders, agrostologists and animal workers and accelerating use of legume-based pastures. Their gross value last year was $1,962 million with export income from wool of $790 million, meat $249 million, and dairy products $107 million. Despite our big expansion in minerals, the pastoral industries at present earn 43 per cent of Australia's export income with agriculture overall earning 69 per cent.

Australia's southern pasture revolution began in the 1930's after Howard's claims about subterranean clover (Hill 1936) had been substantiated by farmers and agricultural scientists. Subterranean clover-based pasture development was generally accepted and proceeded apace, and although interrupted by the 1939-45 war, has resulted in spectacular increases in animal production. Other legumes, including the medics, lucerne and white clover, also became increasingly important in southern pastures. The discoveries of the effects of soil deficiencies in copper-zinc (Riceman 1945), copper (Teakle and Stewart 1939) and molybdenum (Anderson 1942) were vital in maintaining the high rate of pasture improvement.

In Australia over the last 30 years there has been a sixfold increase in area of fertilized pastures to over 41 million acres, paralleled by a similar increase in superphosphate usage to 2.3 million tons. This has been accompanied by an increase of 47 per cent in sheep numbers to 164 million, and 40 per cent in cattle numbers to 18 million of which about one-quarter are dairy cattle. Increases in volume of wool and meat are proportionately greater at 67 and 72 per cent respectively due to increased productivity per animal and quicker turn-off with meat animals. Milk production has increased about 32 per cent.

Donald (1965) in his Farrer Memorial Oration concluded that at least half the increase in Australian wool production from 1947-63 resulted from expansion in area of improved pastures and the concomitant increase in sheep numbers, stocking rate, and fleece weight. Bishop (1964) found that the striking increase in sheep numbers and wool production in the high rainfall zone of Tasmania, Western Dis-

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trict of Victoria, and Southern and Northern Tablelands of New South Wales were due mainly to the use of superphosphate and subterranean clover. He was able to correlate the increased stock numbers with the cumulative total of superphosphate applied and show that from 1946-62 both stock numbers and superphosphate used rose steeply.

There is no doubt that Australia's enhanced prosperity in the last 30 years has been dependent in no small measure on the use of legume-based pastures. Considerable overseas interest has been evinced in the results obtained and Australia has gained a reputation for its work on phosphate-responsive pasture legumes and the role of minor elements in legume nutrition. What of the future? Will the vast potential for pastoral development in our southern and northern zones calculated by Davies and Eyles (1965) continue to be unlocked by the use of legume-based pastures? With the tropical legumes triggering off northern development, it is an appropriate time to consider this question and look at our key legumes and the factors involved in their use.

The Key Legumes

None of our indigenous legumes possess the characters required to make them successful pasture plants. All the key legumes are exotic and respond to superphosphate, and some of them, like subterranean clover, are insignificant in their country of origin.

Subterranean Clover and Townsville Lucerne

Subterranean clover and Townsville lucerne (*Stylosanthes humilis*), the annual pioneer legumes of the south and north respectively, were both accidentally introduced, the first from the Mediterranean about 80 years ago, and the second from Central or South America probably over 60 years ago. Active interest in Townsville lucerne as a pasture plant was stimulated after Shaw (1961) and Norman (1962) showed the marked increases in beef production possible from its use.

In an outline of the history of subterranean clover, Davies (1951) commented that Harrison (1932) gave us the concept of early, mid-season and later flowering strains in this legume and showed that a range of valuable ecotypes occurred in Australia. Many are described by Aitken and Drake (1941) and Gladstones (1966). Cultivars of subterranean clover in demand include Mount Barker, Dwalganup, Tallarook, Bacchus Marsh, Woogenellup, Geraldton, Yarloop and Clare. In a repetition of the subterranean clover story, natural populations of Townsville lucerne in Queensland and the Northern Territory have been shown by Cameron (1965) to contain a wide range of ecotypes. These vary in yield, flowering time, growth habit, stem colour and hardseededness and a few will become new cultivars as they are proving superior to commercial Townsville lucerne.

Subterranean clover and Townsville lucerne both grow well on poor acid soils, are tolerant of aluminium excess (Munns 1965; Andrew 1966*a*) and respond significantly to superphosphate applications in the presence of molybdenum. Unlike subterranean clover, Townsville lucerne grows well on soils low in phosphorus due to the unique ability of its roots to extract this element from sources rather deficient in it (Andrew 1966*b*). Climatic boundaries for the two species do not overlap. The northern boundary for subterranean clover is at the transition from temperate to sub-tropical while in southern Australia it thrives above the 20 inch isohyet but approaches the 15 inch isohyet in a number of areas (Donald 1960*a*). Townsville lucerne thrives in the Northern Territory above the 30 inch isohyet and in Queensland between the 22 and 60 inch isohyets from the central area northwards but does grow in isolated areas in southern Queensland and northern New South Wales.

Apart from their adaptability, the success of subterranean clover and Townsville lucerne is due to high seed yields, ease of re-establishment and tolerance to grazing, stemming in part from moderate palatability. Harvested seed yields in excess of 500 lb per acre are not uncommon, which ensures cheap seed and encourages large-scale sowings. Actual seed yields around 1,000 lb per acre can be expected from good stands, so persistence of these legumes is assured and animals are provided with a protein concentrate after pastures dry off. In northern Australia cattle lick up Townsville lucerne seed from the ground in the dry season. When Townsville lucerne is sown into spear grass (*Heteropogon contortus*) along our north-eastern coast, a two-phase pasture results, spear grass being grazed mainly over the summer and Townsville lucerne in autumn and early winter when it is more palatable.

Annual Medics

The annual medics are the counter-part of subterranean clover in the drier southern areas with rainfalls from 10 to 17 inches, and have transformed both cereal and animal production in many parts of the Australian wheat belt. They are even finding a place in the southern brigalow of Queensland which usually receives some winter rainfall. Seed yields as high as 1,000 lb per acre are obtained under good conditions so re-establishment and persistence are assured. The abundant pods left lying on the soil after maturity are important in the diet of grazing animals. The medics of consequence originated from countries bordering the Mediterranean and include the barrel medics (*Medicago truncatula* var. truncatula) Hannaford, Jemalong and Cyprus, the Strand medic (*Medicago littoralis*) Harbinger, and the Gama medic (*Medicago rugosa*) Paragosa. Hannaford and Jemalong originate from accidental introduction at the end of the last century. The barrel medics and their role in the Australian wheat belt have been reviewed by Amor (1965).

Lucerne and White Clover

Lucerne and white clover, introduced by early English settlers, have had a long history in Australia and were being sown in the 1850's. Both respond to a winter-summer rainfall pattern, lucerne extending into drier areas and white clover confined to the moister. Due to their ability to supply quality feed at critical periods, there will be a steady increase in the acreages of these sown as the factors involved in their establishment and persistence become better known. Hunter River until recently has been the only lucerne cultivar sown, but now there is a demand for the new releases African, Siro Peruvian and Cancreep. White clover cultivars commonly used include Grasslands Huia, Irrigation, Ladino and Louisiana SI. White clover has some tolerance to aluminium and manganese excess and lucerne is intolerant (Kipps 1947; Andrew 1963; Munns 1965) but this is unlikely to prevent the use of lucerne on most soils. At present lucerne is the most important winter-spring legume in the fertile sub-coastal brigalow lands of Queensland. 't Mannetje (1967) found that lucerne can be established with the summer-growing Siratro (*Phaseolus atropurpureus*) and Rhodes grass (*Chloris gayana*) on granitic soils if its seed is lime pelleted. This has paved the way for the use of lucerne in the large belt of spear grass country south of the Tropic.

White clover has been present for many years in coastal New South Wales and extends up along the Queensland coast only as far as Maryborough, but grows well on the elevated moist Atherton Tableland of north Queensland. It has proved its value in pastures on the Wallum of south-east Queensland and on the northern tablelands of New South Wales. Although once of considerable importance on the north coast of New South Wales, white clover declined and so did milk production, but there is now a resurgence of interest here in this valuable legume because of increased knowledge of its nutrient requirements.

Lotononis

Miles Lotononis (*Lotononis bainesii*) is an unusual perennial tropical legume as it is quite frost tolerant and will make limited winter growth. It was collected from the Worcester Veldt Reserve in South Africa by the plant introductionist, J. F. Miles, and originates in the high veldt of the Transvaal. Until it was supplied with its highly specific rhizobium (Norris 1958) its area of adaptation and agronomy could not be studied. Bryan (1961) found that Miles Lotononis thrives only on permeable soils in sub-tropical areas with rainfall exceeding 35 inches, and that in the Wallum it is highly compatible with the aggressive pangola grass (*Digitaria decumbens*). Its strongly stoloniferous habit and small seed, half the size of white clover, offset the low seed yield of 50 to 60 lb per acre.

Siratro and Glycine javanica

Siratro and *Glycine javanica* are perennial prostrate tropical legumes, deep rooting and with the ability to twine around grasses to reach the light. Siratro, released in 1960, was

Plate I — Siratro growing with Nandi Setaria at C.S.I.R.O. Samford Pasture Research Station.

bred from two Mexican ecotypes of *Phaseolus atropurpureus,* one stoloniferous, and the other higher yielding and freer seeding (Hutton 1962). *P. atropurpureus* is predominantly Central American where it is a minor component of the vegetation and often found in dry difficult situations and not usually on wet coastal lowlands. *G. javanica* is mainly African in origin with some types found in southern and South-east Asia (Bogdan 1966). Most forms introduced come from an area encompassed by the north of South Africa, Tanzania, Rhodesia, Zambia and Kenya. Cultivars in Australia are introductions and include Tinaroo from Kenya, Cooper from Tanzania, and Clarence from South Africa, the first two diploids and the last a tetraploid (Pritchard and Wutoh 1964).

Siratro is tolerant of a wide range of soil conditions and grows from the dry fringe of the potential sown pasture area to the coast. However, Glycine lacks adaptability and persists only on fertile permeable soils in moist north-eastern coastal areas and in the brigalow where rainfall is around 30 inches. This may be due to a high lime requirement and intolerance to excess aluminium and manganese (Andrew 1963; 1966*a*) often present in poor acid soils. Siratro establishes quickly from seed but Glycine is slow to establish. Commercial seed yield per acre of Glycine is around 300 lb while Siratro is only about half of this.

Desmodiums

The Desmodiums are interesting perennial tropical legumes tolerant of soil conditions, but need adequate moisture and are confined to coastal areas (Bryan 1966). They are Central and South American in origin, and Greenleaf Desmodium (*D. intortum*) is derived from a mixture of three introductions from El Salvador and Guatemala, while Silverleaf Desmodium (*D. uncinatum*) came from Brazil. They are prostrate and vigorous and eaten readily by cattle in spite of their relatively high tannin content (Hutton and Coote 1966). Both legumes are susceptible to the ubiquitous disease legume 'little leaf' which affects their persistence in some areas. Greenleaf is hardier and more vigorous than Silverleaf but is slower to establish. Its seed yield of 75 to 100 lb per acre compares unfavourably with Silverleaf's 150 to 200 lb.

Leucaena

The tree *Leucaena leucocephala* is indigenous in Central America and has become naturalized around the coast of northern Australia and in Hawaii, the Philippines, Jamaica, Fiji, New Guinea and other tropical countries. It is deep-rooted and drought-resistant and adapted to any well-drained soil in our tropical areas with a rainfall exceeding 30 inches and with a minimum of frost. Hutton and Gray (1959) calculated a potential of some 96 million acres for Leucaena in Australia. The two present cultivars, Peru and El Salvador, yield ample seed. It is sown in rows about 10 feet apart with hot-water treated seed (Gray 1962) and given inter-row cultivation until well established. Planting an associate grass, pangola, guinea or Setaria, then gives an unusual two-level pasture which will give high liveweight gains in cattle. Although Leucaena herbage is of high quality and contains a higher than usual 4 per cent nitrogen as protein, there has been a cautious approach to its use as it has an additional 0.5 per cent nitrogen as mimosine, an undesirable depressant of cell division (Hegarty *et al.* 1964). It causes wool shedding in sheep, but in cattle only the loss of a few tail hairs. However, there has been some concern that reproduction in cattle could be affected. This has been allayed by a recent experiment in which a number of dairy heifers fed exclusively on Leucaena all conceived and had a normal pregnancy. Apparently the bovine rumen is able to convert mimosine into harmless compounds.

Legume Improvement

Improving the key pasture legumes is difficult and challenging as any new bred line has to fit into the soil-grass-animal system better than current cultivars. Breeding objectives have to be clearly defined if progress is to be made. These can only be deduced from a thorough knowledge of the reaction of the legumes in pastures under different environmental conditions. Knowledge is also needed of the reaction of the legumes to photoperiod, temperature, induced stresses, and to various soil nutrients and toxicities. In fact, progress in breeding will only become more rapid when the biochemical and physiological bases for the important characters in pasture legumes are better understood. To attain the required objectives it is also essential to have a knowledge of the breeding system and cytology of the legumes as well as information on quantitative inheritance of the important characters. It must not be overlooked that progress in improvement, especially the self-pollinators, can be retarded until suitable hybridization techniques are available. These have been developed for subterranean clover (Hutton and Peak 1954), the medics (Simon 1965*a*), Leucaena (Hutton and Gray 1959), and some of the other tropicals (Hutton 1960).

There is hardly need to stress the importance of having a large gene pool of the legumes by having plant introductionists assemble as wide a range of the species as possible from all areas where the species grow naturally. It is one thing to have a gene pool and another to make the best use of it. The breeder needs to be adventurous and aim at making crosses between widely divergent types with different geographical origins if he is to achieve new gene interactions and valuable transgressive segregates with a wider range of adaptability. Inferior looking types should not be neglected in crosses if they come from unusual ecological niches, as they could produce progenies with new characteristics. No one can predict what will happen with such crosses until they are made.

The main Australian centres concerned with breeding pasture legumes are the Institute of Agriculture, University of Western Australia, C.S.I.R.O. Division of Plant Industry, Canberra, and the C.S.I.R.O. Division of Tropical Pastures at Brisbane and Townsville. A useful programme is also being developed by the Queensland Department of Primary Industries at the Parada Research Station in north Queensland. There is thus a geographical spread of activity from the extreme Mediterranean environment to the really tropical.

Breeding Temperate Legumes

Subterranean Clover

Breeding and genetical work with subterranean clover is discussed by Morley (1961) in a review concerning this legume. A significant finding from a wide range of crosses is the occurrence of intraspecific sterility barriers (Morley *et al.* 1956) which have enabled the classification of strains into six 'sub-species'. The wealth of subterranean clover introductions and the excellence of established cultivars have posed the breeder a difficult problem. In spite of this, Francis and Millington (1965) made a distinct advance with the release of the isoflavone mutant Uniwager with extremely low oestrogenic activity. High oestrogenic activity of subterranean clover pastures and attendant infertility in ewes has been a perennial problem, particularly in Western Australia. Another step forward was made by Grylls and Peak (1960) who located genotypes resistant to the serious virus stunt and this led to the breeding of the resistant variety Howard (Peak and Morley 1963).

Medics

In his review Amor (1965) mentions breeding work done by the Victorian Department of Agriculture and Waite Institute with medics. The first published work comes from the Institute of Agriculture, Western Australia (Simon 1965*a*, 1965*b*; Simon and Millington 1967). Intraspecific hybrids of *M. truncatula* were highly fertile while those of *M. littoralis* had low fertility. However, viable hybrids were obtained with ease between these two species and could produce cultivars with adaptation to a wide range of soils. Interspecific hybrids were obtained with some difficulty between *M. tornata* and *M. littoralis* and were of low fertility.

Lucerne

Lucerne's role in pastures will definitely expand in the years ahead, so new cultivars adapted to grazing are required. This need is being met by two programmes, one at the Division of Plant Industry, Canberra, the other at the Cunningham Laboratory, Brisbane, to breed temperate and sub-tropical grazing lucernes respectively. Both are based on Rambler bred by Heinrichs (1954) in Canada. Part of this cultivar's root system spreads four to six inches below the soil surface and develops buds which give rise to sub-surface shoots and crowns so it persists and thickens up under grazing. At Canberra, Daday's (1962) crosses showed that it would be possible to combine the creeping-rooted habit of Rambler with the summer and winter vigour of the varieties Hunter River, Hairy Peruvian and African. This work has resulted in the release of Cancreep, an Australian creeping-rooted lucerne for temperate conditions (Daday *et al.* 1968).

In the sub-tropics, commercial Hunter River lucerne persists only a few years due to rotting of ageing crowns so persistence is a major consideration. At Lawes, south-east Queensland, Edye and Haydock (1967) studied inheritance and association of creeping-rootedness and yield in intercrosses between Rambler selections and a range of varieties. A number of high yielding creeping-rooted lines with active winter and early summer growth resulted. In progenies of these Bray (1967, 1968) showed a high correlation between creeping-rootedness and both survival and yield. It now seems that a high yielding sub-tropical grazing lucerne will be bred which will be able to persist because

Plate II — Leucaena showing flowers and pods and habit of growth.

of replacement of dead crowns with young vigorous ones. Its use will increase pasture quality when it is low during winter to early summer in the brigalow and spear grass areas of southern Queensland.

White Clover

In spite of the desirable agronomic features and high quality of white clover, it is only recently that some breeding work has been commenced with this legume in Australia. Perhaps its considerable variability has been a deterrent to plant breeders. In south-east Queensland and on the Atherton Tableland, white clover is mainly annual and in unimproved pastures the naturalized type is low yielding and small-leaved. With the introduction of a cultivar like Ladino, adequate superphosphate and other fertilizers, the two types intercross and there is a rapid emergence of vigorous leafy strains better adapted to the more fertile environment. Single plant studies have revealed that these are intermediate in type and predominantly annual.

Breeding Tropical Legumes

A number of the tropical legumes used in Australia have a short history as pasture plants and commercial seed has been available for only five to six years. They were selected because of persistence under grazing in our dry tropics with its variable summer rainfall, winter drought and southern Queensland frosts. Most are superior to temperates in extracting calcium from the soil so nodulate at low calcium levels (Andrew and Norris 1961). All possess some undesirable 'wild' characters which will eventually be eliminated by breeding programmes in progress. Doubt has often been expressed about nitrogen fixation of tropical legumes, but Henzell (1962) has shown this to be almost as good as that of white clover under optimum conditions. Jones *et al.* (1967) found that the increase in total nitrogen yield of pasture from inclusion of tropical legumes was directly related to legume yield. With high potential grass production in the tropics (Henzell 1963) the main breeding problem with tropical legumes is to increase their yielding ability and the dry matter they contribute to the pasture. This would not only supply more nitrogen to approach potential pasture yield, but would increase feeding value which tends to be low in tropical pastures. Compared with tropical grasses the tropical legumes have a significantly higher content of digestible crude protein and are eaten in greater quantities (Milford and Minson 1966).

Greater tolerance of tropical legumes to heavy grazing is also required and may be achieved by breeding for more buds and growing points per unit area. Also, it must not be overlooked that as larger areas of the tropical legumes are grown, they will become hosts to various pests and diseases so that breeding for resistance to these may be needed.

Townsville Lucerne

Following Cameron's (1965) discovery of extensive variation in naturalized Townsville lucerne, erect, early, mid-season and late ecotypes proved to have the highest yields (Cameron 1967*a*), due no doubt to greater tolerance to grass shading. The best of these will be released and the marker characters, pale pods and dark seeds, are being added to aid in their identification.

In diallel crosses involving Australian ecotypes, Cameron (1967*b*) found that late flowering was dominant. The interspecific Stylosanthes hybrids he produced were sterile, but from *S. humilis* × *S. hamata* he has developed a fully fertile tetraploid line with colchicine. It is apparent that significant advances are near in Townsville lucerne and associated Stylosanthes species.

Siratro

Since the release of Siratro eight years ago, its large-scale use has revealed several deficiencies. These include low commercial seed yields due to shattering of ripening pods, restriction of growing season south of the Tropic from intolerance to the lower autumn to spring temperatures, and leaf and stem damage from the ubiquitous *Rhizoctonia solani*. After the release of Siratro, intercrosses were made between Siratro selections and a few other *P. atropurpureus* introductions available at the time. In the progenies a high correlation was found between yield and stoloniferous development, this latter character thus expressing inherent vigour. From this work fixed bred lines more stoloniferous and higher yielding and better able to compete with grasses than Siratro have resulted. Like Siratro, these have low commercial seed yields and lack the ability to grow under cooler conditions. However, a proportion of the lines show a high resistance to leaf damage from Rhizoctonia which is encouraging.

Four years ago another and larger range of crosses were made between ecotypes from a new and extensive Central American collection of *P. atropurpureus* and the best of the bred lines resulting from the previous Siratro crosses. This latest series now in the F_4 has given a good proportion of most promising lines in which high dry-matter yield has been maintained. A number of these have greater cold tolerance and a markedly longer growing season than Siratro, and some also combine a minimum of pod shattering under hot dry conditions, which cause almost complete pod shattering in Siratro. It now seems that it may be possible to combine all the required characters into a number of new lines. Before any of these are released as a replacement for Siratro, their adaptability to the wide range of conditions in northern Australia must be properly assessed. In addition, they need to have a high resistance to *Rhizoctonia solani* and at least maintain the high resistance of Siratro to root-knot nematode and legume 'little leaf'.

Glycine javanica

Lack of adaptability of Glycine and its slow establishment may be overcome by breeding programmes in progress at Parada in north Queensland and the Cunningham Laboratory, Brisbane. The cultivars Cooper and Clarence have proved more adaptable than Tinaroo so crosses involving these could result in lines with adaptation to a wider range of soils. Incorporation of larger seeds and quicker nodulation in the new bred lines could overcome establishment problems.

In a diallel cross of five Glycine introductions Wutoh *et al.* (1968*a*) showed that there was no correlation between yield and flowering time and that genetic advance could be made in flowering time, maturity date and seed weight but would be limited for yield and stolon development. A further series of crosses (Wutoh *et al.* 1968*b*) have shown that early flowering, high yield, and good stolon development could be combined — a distinct advantage when breeding lines for drier environments.

Desmodiums

The Desmodiums are both self- and cross-pollinated, so pose some breeding problems. *D. intortum* and *D. sandwicense* cross with ease (McWhirter 1963) and promising fully fertile lines from this combination are early and hardy and could have a place in drier areas. Crosses within *D. intortum* and between *D. intortum* and *D. uncinatum* (Hutton and Gray 1967) have the most promise and are producing early vigorous lines with high seed yields and ability to continue growth after seeding.

No introduced lines possess a high level of legume 'little leaf' resistance but there is some indication that a useful degree of field resistance is present in the progenies of some recent crosses. The somewhat slow establishment of *D. intortum* may be caused by delayed nodulation so genetic work on the rate of nodulation is in progress. A difficult problem with Desmodium in some areas is reduced persistence due to larvae of the Amnemus weevil feeding on the roots in winter (Mears 1967). Until more is known about the ecology and physiology of Amnemus and associated weevils no progress can be made in breeding for resistance.

Leucaena

There is no urgency to breed mimosine-free lines of Leucaena for cattle pastures since most of the mimosine is destroyed in the rumen. Cattle eat only leaves and twigs 0.25 inch or less in diameter so the aim has been to breed lines with as high a proportion of leaf to wood as possible, and with a short bushy habit which keeps the herbage within reach of the animal. Gray (1967) made intercrosses between the tall sparsely branched Guatemala and El Salvador, the multi-branched Peru, and the short bushy Hawaii. The tall sparsely branched habit was dominant over the multi-branched and short bushy habits, and superior lines combining high leaf yield with a dense compact branching habit suitable for grazing were obtained, particularly from the cross Hawaii × Peru. Adaptability of the new bred lines is being studied in a range of environments and some are proving superior to the current cultivars so will be considered for release in the future.

Role of Key Legumes in Pastures

Nitrogen Fixation

Eight years ago, Donald (1960*b*) calculated that one million tons of soil nitrogen per annum worth about $260 million was being added by legumes to 25 million acres of southern pastures topdressed with superphosphate. Since then, there has been a 60 per cent increase in pasture area and superphosphate used so the annual value of the nitrogen added based on urea would now be in excess of $300 million. However, as pointed out by Donald (1965), the worth of this vast bank of nitrogen is the extent to which it can be converted into crops, meat or wool. Production of the main commodity, wool, causes little drainage of the fertility input so an inefficient biological system is involved with equilibrium at high fertility instead of heavy input and exploitation. This poses a major problem to agricultural scientists in southern Australia who need to find suitable annual crops to integrate with improved pastures.

Henzell (1968) estimated that the range of nitrogen fixation by tropical legumes in northern Australia is 20-260 lb an acre a year depending on level of legume yield. At Beerwah, a moist coastal area 50 miles north of Brisbane, *D. uncinatum* increased soil nitrogen by 30-77 lb an acre a year according to amount of applied superphosphate (Henzell *et al.* 1966). Under Townsville lucerne at Rodd's Bay, Central Queensland, about 50 lb soil nitrogen an acre a year is added in favourable seasons, but in three dry ones there was a loss of 23 lb of soil nitrogen an acre a year (Vallis, pers. comm.). Henzell (1968) concluded that growth of tropical pasture legumes does not necessarily increase soil nitrogen and asked whether there is any benefit from rapid build-up of soil nitrogen in view of its low availability.

It could well be that under drier conditions in northern Australia rate of loss of nitrogen is often so rapid that soil nitrogen accretion from legume growth is negligible. Logically then the main aim in tropical legume breeding as mentioned earlier should be to increase both yield and proportion of the legume in the pasture.

Dry Matter and Animal Production

Estimates of dry-matter and protein production of our pasture legumes vary considerably and it is difficult to obtain average figures. With barrel medic pastures, Amor (1965) concluded that annual dry-matter production averages less than one ton an acre, and ranges from a few cwt to 2.5 tons an acre, and that carrying capacity varies from 0.5 to three dry sheep an acre. Amor's (1966) Walpeup experiments involving three barrel medics and Harbinger medic gave dry-matter yields as high as 6,000 to 7,000 lb in a good season but as low as 500 to 850 lb in a poor season. Seasonal pod yield per acre was substantial and varied in the barrel medics from around 500 lb up to 2,000 lb with Harbinger as high as 3,400 lb. During summer the pods give valuable feed as half a ton of pods per acre provides 200 lb of protein.

Donald (1951) considered that approximately four tons of dry matter per acre per annum is the maximum yield obtainable by subterranean clover in pure stand. According to the results of different workers, annual total dry-matter yields per acre of subterranean clover-based pastures topdressed each year with one to two cwts superphosphate per acre usually vary from 2,000 to 8,000 lb (Anderson and McLachlan 1951; Willoughby 1954; Rossiter 1964). Under 'steady state' conditions subterranean clover constitutes 20 to 40 per cent of the yield but a cycle of clover dominance commonly occurs particularly with lighter superphosphate applications. Willoughby's (1959) experiment at Canberra with pastures of subterranean clover / *Phalaris tuberosa* grazed at six different pressures through the year with a mean of four sheep per acre, showed that less than one-third of the liveweight gain potential of the pasture was attained on any one of the systems used. This experiment was considered by Morley (1961) to demonstrate the possibility of stocking rates up to eight sheep per acre on unirrigated subterranean clover-based pastures. Achievement of such a grazing pressure would be assisted by large quantities of protein-rich clover seed often produced at the soil surface. Willoughby's (1959) work has in fact triggered off a move towards greater utilization of southern legume-based pastures through increased stocking rates. For example, Carter (1968) at the Waite Institute using a subterranean clover/ Wimmera rye grass pasture found over a range of seasons that the optimum stocking rate was seven wethers per acre, which gave 99 to 107 lb greasy wool per acre and 75 to 83 per cent utilization of the 8,600 to 13,700 lb per acre of dry matter produced.

Some of the first animal production data in northern Australia with a legume was obtained by Christian and Shaw (1952) who found that inclusion of a small percentage of lucerne in Rhodes grass pastures increased both grass growth and liveweight gains of steers out of all proportion to the amount of lucerne present. At Katherine, Northern Territory, Norman and Arndt (1959) fed cattle from native pasture on a Cenchrus/Townsville lucerne mixture in the dry season and converted the usual weight loss into a gain. This work was followed up by Norman (1962) who obtained mean annual dry-matter yields per acre of 3,200 lb for Townsville lucerne alone and 4,800 for a spaced *Cenchrus setigerus*/Townsville lucerne mixture comprising 54 per cent legume. Corresponding annual nitrogen yields per acre were 72 lb for Townsville lucerne and 80 lb for the mixture in which 73 per cent was contributed by the legume.

Shaw (1961) at Rodd's Bay, Central Queensland, has proved that inclusion of Townsville lucerne in native spear grass pastures and annual applications of one cwt molybdenized superphosphate increases carrying capacity of steers three times to one beast to three acres. The annual liveweight gain per acre increases at least five times and animals can be marketed one to two years earlier than those on native pasture. Dry-matter yields of these and other improved Townsville lucerne/ spear grass pastures in the 28 to 35 inch rainfall areas vary according to season and district from 5,000 to 10,000 lb per acre per annum, the legume being 30 to 40 per cent of the yield. On comparable pastures at Lansdown near Townsville, Edye and Ritson (Ritson 1967) obtained similar increases in liveweight and stocking rate to Shaw (1961). However they used breeding Droughtmaster cows and found striking increases in calf production. Mean calving percentages for nil and one cwt per acre and three cwt per acre of superphosphate were 47, 78 and 85 respectively. Pasture improvement in the spear grass zone is profitable (Haug and Hirst 1967) and the results obtained there have had a marked influence on increasing the tempo of pasture development in northern Australia. Favourable results are also being obtained in other areas including the coastal Sandy Wallum which extends from Gladstone to Coff's Harbour. At Beerwah, a typical Wallum site, Bryan and Evans (1967) have produced 429 lb liveweight gain per acre in a year with steers at one beast to the acre on a fertilized pasture of pangola grass, Desmodiums, Lotononis and white clover. The potential annual dry-matter yield per acre of this pasture is about 16,000 lb and comprises 40 per cent of legume on the average.

Feeding Value

The intake of digestible dry matter is the main factor determining animal production so high intake of feed is necessary for rapid growth and high meat and milk yields. Between sheep of normal genetic diversity grazing the same pastures, Schinckel (1960) concluded that a significant proportion of the differences in clean wool production is due to differences in feed intake. Temperate legumes are more digestible

Plate III — Townsville lucerne growing at C.S.I.R.O. Lansdown Research Station near Townsville.

than tropical and neither are markedly different in digestibility from the corresponding grasses. However the voluntary intake of legumes is usually much higher than that of grasses of similar digestibility (Milford and Minson 1965).

As stated, intake is the main determinant of feeding value. For over half the year feeding value of our pastures is too low and the available dry matter is only capable of maintaining animals. The ratio of liveweight gain of beef cattle to the dry matter grown is of the order of 1:20 for improved temperate pastures and 1:40 for improved tropical pastures. It is apparent that efficiency of our pastures, particularly the tropical, as food for livestock needs considerable improvement. This can only be achieved by improving animal intake of pasture, so more per acre is eaten and less dry matter per unit of animal production is needed. At present a high proportion of the dry matter grown is wasted and with tropical pastures it is thought that only about 30 per cent is eaten.

The most positive way to increase intake and efficiency of conversion of pastures is to increase their legume content and this applies especially to tropical because of the rapid fall in feeding value of tropical grasses after the young leaf stage. With legume-based pastures in southern Australia, increased stocking rate as shown by Carter (1968) results in high utilization of the dry matter produced. In Western Australia Fels *et al.* (1959) found a much greater intake of subterranean clover than grass in grazing sheep during September when growth is rapid. Also of interest is Butler *et al.*'s (1968) work in New Zealand with a range of pastures in which highest liveweight gains were obtained from sheep grazing white clover alone. As indicated, the need to increase feeding value and utilization of tropical pastures is pressing and it is fortunate that tropical legumes, in spite of apparent coarseness, maintain a high intake throughout the season (Milford and Minson 1966). Increased legume content of tropical pastures may be obtained by management and as mentioned earlier by breeding higher yielding and more vigorous legumes. Conversely, it may be feasible to breed less vigorous tropical grasses which offer only moderate competition and allow an increased proportion of legume in the pasture.

What is the Future for Legumes?

Legume v. Fertilizer Nitrogen

With the prospect of large amounts of relatively cheap nitrogenous fertilizers becoming available in Australia in the near future, some consider it is only a matter of time before legumes will be relegated to a minor role in our pastures. This was not the conclusion at the recent (May 1968) Australian Grassland Conference in Perth. Delegates agreed that legumes will continue to be dominant in most situations but will be increasingly complemented and sometimes displaced by nitrogenous fertilizers in higher rainfall areas with an extended growing season and where cheap irrigation water is available. There is a need to find legume/grass combinations which tolerate periodic nitrogen applications made to stimulate growth when feed is scarce. White clover is one legume tolerant of nitrogen fertilization, provided the pasture is kept short. Use of large amounts of nitrogen fertilizer demands superior management to ensure a profitable return on the extra investment. Maintaining good intake of the bulk of grass produced is difficult without careful attention to stocking rate. Also elimination of the legume in favour of nitrogen-fertilized grass does not remove the need for superphosphate and potassium fertilizers.

Profitability of production from nitrogen-fertilized grass is a vexed question. Henzell (1968) has endeavoured to assess it in the Wallum of south-east Queensland where conditions are particularly favourable for nitrogen fertilization. Based on pangola grass and two steers per acre, he calculated that for the operation to be profitable nitrogen would need to be two cents a pound and not the present nine cents as urea. Jones (pers. comm.) has also made some interesting calculations based on experiments at the Samford Pasture Research Station. Annual crude protein production per acre from grass pasture fertilized with superphosphate and potassium chloride is 370 lb but is 1,000 to 1,250 lb when the same pasture includes Siratro, and 1,600 lb when 300 lb of nitrogen is added to it. With one steer to 1.5 acres on the legume-based pasture, cost per lb of animal protein is 16 cents whereas it is 28 cents per lb for the nitrogen-fertilized grass with two steers per acre. The difference in favour of legume nitrogen can be offset where land values and rentals are high. In the Rodd's Bay area with fertilized Townsville lucerne, cost per lb of animal protein is only 10 cents, even allowing for rental.

Can Legumes meet Future Protein Needs of our Pastoral Industries?

Extensive methods will be used in Australia's pastoral industries for a very long time. Though the climate is uncertain and droughts more frequent than we would like, we are blessed with adequate land. The grazing ruminant, although an inefficient food converter by some standards, is ideal for our pastoral situation, as it is an efficient and inexpensive gatherer of herbage scattered over large areas. Relatively rough plant food is inexpensively converted into high quality animal protein. The cost of replacing the ruminant and harvesting the protein from our extensive areas by mechanical and chemical methods would be prohibitive and the protein would never be as tasty as a piece of steak. However, pasture workers must not be complacent as industrial harvesting of protein from legumes and nitrogen-fertilized grass grown under irrigation could become economic if yields were high enough and irrigation and extraction processes cheap enough. The challenge is to increase legume yields and amount of legume in our pastures to increase their efficiency of conversion by the ruminant. The central fact is that legumes give a significantly greater animal intake of digestible energy than grasses, as well as much larger amounts of crude protein and other nutrients.

As stated earlier, Australia now has over 41 million acres of pasture fertilized with superphosphate and most would be legume-based. Of this, not more than one million acres would be in the northern zone, north of latitude 30°S., as defined by Davies (1961). A proportion of the extensive area of clay loams in the rapidly developing brigalow area of Queensland is sown to pasture, but is not fertilized because of its inherent fertility. Davies and Eyles (1965) have estimated that in the better rainfall areas, Australia could ultimately have 110 million acres of improved pasture in the southern zone carrying 450 million sheep and 25 million cattle and 260 million acres in the northern zone carrying 60 million cattle.

It is of interest to calculate the crude protein requirements of this huge potential animal population and balance this against the crude protein production which could be expected from legume-based pastures. From studies of the nutrient requirements of ruminants (*Nutrient Requirements of Domestic Animals* 1963, 1964) and allowing for digestibility, it appears that for cattle 1.3 lb crude protein per animal per day is needed for maintenance and moderate liveweight gain, and for sheep 0.3 lb crude protein per animal per day is needed for maintenance and wool growth. These figures are conservative, and would allow for the range of ages in the animal population. If the sheep and cattle populations predicted by Davies and Eyles (1965) are ever reached, the annual crude protein requirements in the southern zone would be of the order of 27 million tons and in the northern zone, 11 million tons.

In the States of southern Australia, except drier South Australia and moister Tasmania, about one-third of the present and potential pasture areas are between the 15 inch and 20 inch isohyets, the rest receiving more than 20 inches annual rainfall. If annual dry-matter yields per acre of 3,360 lb of medic or its equivalent and 7,000 lb containing 40 per cent of subterranean clover are assumed for the drier and moister parts respectively of the potential area of improved pastures in southern Australia, crude protein production would be about 30 million tons. This would readily cover future animal requirements here.

In the northern zone, about half the potential improved pasture area is below 30 inches annual rainfall with the rest above. If annual dry-matter yields of 4,000 lb and 8,000 lb with a legume content of 30 per cent are assumed for the drier and moister parts respectively, a total crude protein yield of 37.5 million tons could be contemplated. This is over three times the future estimated animal requirement for protein in the northern zone. These comparative figures are interesting and emphasize the tremendous potential inherent in northern Australia due to availability of land which can now grow improved pastures as a result of recent research. The calculations also clearly indicate the vital role of legumes in the future development of our pastoral industries.

Legumes in Developing Countries

Underwood (1967) in his Farrer Oration directed attention to the impact which legumes could have in developing countries where soil fertility is generally low. There, the need is urgent for productive leguminous crops and pastures with high nitrogen fixation to overcome lack of protein, the most serious and widespread deficiency, and to obviate the necessity for expensive nitrogenous fertilizers. Australia is one of the few more developed countries where pasture legumes will continue to have a dominant role and where expertise with both temperate and tropical legumes is available. Underwood (1967) strongly suggests that we should accept the challenge and take this expertise to the developing countries and so help them raise their agricultural productivity. We agree with Underwood (1967) and it is pleasing that there is now substantial interchange on pasture legumes with scientists from a range of developing areas, including South-east Asia, the Philippines, India, Africa and temperate and tropical parts of South America. These scientists have been stimulated to experiment with our legumes and also collect seed of their native legumes. This has been mutually beneficial as we have gained considerable knowledge on the reaction of our legumes in a wide range of environments and have been given seed of numbers of exotic legumes, which is proving invaluable in our selection and breeding programmes. Varying quantities of seed of Australia's pasture legumes are now being imported into a number of countries. Subterranean clover is having a decided impact in Uruguay which is now a substantial customer for seed of this legume. Promising results have been reported for a number of the tropical legumes, e.g. for Stylo in Ceylon and the Ivory Coast, Townsville lucerne in Burma and Laos, the Desmodiums in Kenya, and Siratro in Bolivia, Mexico, Tanzania and even Rajasthan (Patil *et al.* 1967).

In the tropics it has been calculated that 10 per cent is cropped, 20 per cent is pasture, 35 per cent is forest, and a third is waste land. Most of the pasture used is indifferent and would benefit by inclusion of legumes. Forest areas and wastelands are usually in hilly country and the sporadic attempts to crop them have almost invariably resulted in soil erosion. Immense benefits can be expected from the development of idle uplands and current pasture areas in the tropics by planting legume-based pastures. Knowledge of soil nutrient requirements is a vital link and fertilization with superphosphate, often potash, and usually with minor elements like molybdenum and copper is frequently essential. There is no doubt that close attention to pasture development, based on the new knowledge available, would markedly increase productivity in the tropics and make the essential meat and milk cheaper and more readily available.

A Change in the Structure and Physiology of Future Legumes?

With the need to obtain still more digestible protein and energy from our pasture environments as costs and land values rise, it will be necessary to consider how we can make our legumes more efficient in the use of moisture, solar energy and soil nutrients. Our New Zealand colleagues have already felt this need and Mitchell (1966) has considered high efficiency forage crops which can supplement or displace their productive and attractive white clover/rye grass pastures. On the Canterbury Plain in the South Island of New Zealand rotationally grazed lucerne is yielding 18,000 lb dry matter per acre per annum and giving higher weight gains in sheep than white clover/rye grass pastures. Perhaps we should give far more attention to lucerne as it uses light more efficiently than a number of legumes. Lupins are also more efficient and the Agronomy Department of the University of Western Australia is already doing breeding work with this species. The potential in leguminous shrubs and trees must not be overlooked, as they can be used with grasses in a two-layer system which makes good use of light energy. As mentioned earlier, the combination of the tree legume Leucaena with a number of grasses is starting to be used with good effect in northern Australia.

Since animal intake of digestible protein and energy is much higher for legumes than grasses, it is logical to think about changing the geometry of our legumes and breeding tall, bulky, rather coarse types. To give the highest return of digestible nutrients per acre, these could be grown in monospecific stands from which grass and weeds were eliminated by herbicides. In northern Australia we already have tall bulky species like *Dolichos lab lab* and there is no reason why still higher yielding types could not be bred. Coupled with breeding for changed structure is a need to breed for still higher digestibility and intake as well as for higher efficiency in the uptake of vital nutrients like phosphorus and potassium. With their exposed buds, such legumes may need special grazing management to obtain the best returns from them. Will the plant breeder be able to accept the challenge and develop legumes more closely fitted to the needs of our burgeoning animal industries?

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References

Aitken, Yvonne, and Drake, F. R. (1941)—*Proc. R. Soc. Vict.* **53:** 342-93.
Amor, R. L. (1965)—*J. Aust. Inst. agric. Sci.* **31:** 25-35.
Amor, R. L. (1966)—*Aust. J. exp. Agric. Anim. Husb.* **6:** 361-4.
Anderson, A. J. (1942)—*J. Aust. Inst. agric. Sci.* **8:** 73-5.
Anderson, A. J., and McLachlan, K. D. (1951)—*Aust. J. agric. Res.* **2:** 377-400.
Andrew, C. S. (1963)—Manganese excess. Rep. Div. Trop. Past. C.S.I.R.O., pp. 35-6.
Andrew, C. S. (1966*a*)—Aluminium excess. Rep. Div. Trop. Past. C.S.I.R.O., p. 63.
Andrew, C. S. (1966*b*)—*Aust. J. agric. Res.* **17:** 611-24.
Andrew, C. S. and Norris, D. O. (1961)—*Aust. J. agric. Res.* **12:** 40-55.
Bishop, A. H. (1964)—*J. Aust. Inst. agric. Sci.* **30:** 219-31.
Bogdan, A. V. (1966)—*Trop. Agric. Trin.* **43:** 99-105.
Bray, R. A. (1967)—*J. Aust. Inst. agric. Sci.* **33:** 46-7.
Bray, R. A. (1968)—*Aust. J. agric. Res.* (In press).
Bryan, W. W. (1961)—*Aust. J. exp. Agric. Anim. Husb.* **1:** 4-10.
Bryan, W. W. (1966)—The pasture value of species of Desmodium. *Proc. 10th Internat. Grassld Congr. Helsinki.* Sect. 1, Paper 54.
Bryan, W. W., and Evans T. R. (1967)—Coastal lowlands—Grazing experiments with mixed pastures. Rep. Div. Trop. Past. C.S.I.R.O., p. 20.
Butler, G. W., Rae, A. L., and Bailey, R. W. (1968)—*N.Z. agric. Sci.* (In press).
Cameron, D. F. (1965)—*Aust. J. exp. Agric. Anim. Husb.* **5:** 49-51.
Cameron, D. F. (1967*a*)—*Aust. J. exp. Agric. Anim. Husb.* **7:** 501-8.
Cameron, D. F. (1967*b*)—Stylosanthes species. Rep. Div. Trop. Past. C.S.I.R.O., pp. 98-101.
Carter, E. D. (1968)—The effect of stocking rate on the production and utilization of annual pasture and on wool production. Contributed Papers and Reviews, Aust. Grassld Conf. Vol. 1.
Christian, C. S. and Shaw, N. H. (1952)—*Aust. J agric. Res.* **3:** 277-99.
Daday, H. (1962)—*Aust. J. agric. Res.* **13:** 813-20.
Daday, H., Peak, J. W., Launders, T., Cameron, D. J., Campbell, G. B., Crawford, E. J., and Ryan, F. E. (1968)—*Aust. J. exp. Agric. Anim. Husb.* (In press).
Davies, J. G. (1951)—*J. Aust. Inst. agric. Sci.* **17:** 54-66.
Davies, J. G. (1961)—Pasture and forage legumes for the dry sub-tropics and tropics of Australia. *Proc. 8th Internat. Grassld Congr. Reading,* pp. 381-5.
Davies, J. G., and Eyles, A. G. (1965)—*J. Aust. Inst. agric. Sci.* **31:** 77-93.
Donald, C. M. (1951)—*Aust. J. agric. Res.* **2:** 355-76.
Donald, C. M. (1960*a*)—*Herbage Abstr.* **30:** 81-90.
Donald, C. M. (1960*b*)—*J. Aust. Inst. agric. Sci.* **26:** 319-38.
Donald, C. M. (1965)—Farrer Memorial Oration. *Aust. J. Sci.* **27:** 187-98.
Edye, L. A., and Haydock, K. P. (1967)—*Aust. J. agric. Res.* **18:** 891-901.
Fels, H. E., Moir, R. J., and Rossiter, R. C. (1959)—*Aust. J. agric. Res.* **10:** 237-47.
Francis, C. M. and Millington, A. J. (1965)—*Aust. J. agric. Res.* **16:** 565-73.
Gladstones, J. S. (1966)—*Aust. J. Bot.* **14:** 329-54.
Gray, S. G. (1962)—*Aust. J. exp. Agric. Anim. Husb.* **2:** 178-80.
Gray, S. G. (1967)—*Aust. J. agric. Res.* **18:** 63-70.
Grylls, N. E., and Peak, J. W. (1960)—*Aust. J. agric. Res.* **11:** 723-33.
Harrison, J. E. (1932)—*J. Dept. Agric. Vic.* **30:** 505-11.
Haug, N. F., and Hirst, G. B. (1967)—*Quarterly Rev. agric. Econ.* **20:** 113-26.
Hegarty, M. P., Schinckel, P. G., and Court, R. D. (1964)—*Aust. J. agric. Res.* **15:** 153-67.

Heinrichs, D. H. (1954)—*Can. J. agric. Sci.* **34:** 269-80.
Henzell, E. F. (1962)—*Aust. J. exp. Agric. Anim. Husb.* **2:** 132-40.
Henzell, E. F. (1963)—*Aust. J. exp. Agric. Anim. Husb.* **3:** 290-9.
Henzell, E. F. (1968)—Sources of nitrogen for Queensland pastures. *Tropical Grasslands* (In press.)
Henzell, E. F., Fergus, I. F., and Martin, A. E. (1966)—*Aust. J. exp. Agric. Anim. Husb.* **6:** 157-60.
Hill, R. (1936)—*J. Agric. S. Aust.* **40:** 322-30.
Hutton, E. M. (1960)—*Emp. J. exp. Agric.* **28:** 235-43.
Hutton, E. M. (1962)—*Aust. J. exp. Agric. Anim. Husb.* **2:** 117-25.
Hutton, E. M., and Coote, J. N. (1966)—*J. Aust. Inst. agric. Sci.* **32:** 139-40.
Hutton, E. M., and Gray, S. G. (1959)—*Emp. J. exp. Agric.* **27:** 187-96.
Hutton, E. M., and Gray, S. G. (1967)—*J. Aust. Inst. agric. Sci.* **33:** 122-3.
Hutton, E. M., and Peak, J. W. (1954)—*Aust. J. agric. Res.* **5:** 271-8.
Jones, R. J., Davies, J. G., and Waite, R. B. (1967)—*Aust. J. exp. Agric. Anim. Husb.* **7:** 57-65.
Kipps, E. H. (1947)—*J. Coun. Sci. Ind. Res. Aust.* **20:** 176-89.
McWhirter, K. S. (1963)—Desmodium. Rep. Div. Trop. Past. C.S.I.R.O., p. 32.
't Mannetje, L. (1967)—*Tropical Grasslands* **1:** 9-19.
Mears, P. T. (1967)—*Tropical Grasslands* **1:** 98-105.
Milford, R., and Minson, D. J. (1965)—Intake of tropical pasture species. *Proc. 9th Internat. Grassld Congr. Sao Paulo, Brazil,* p. 815-22.
Milford, R., and Minson, D. J. (1966)—The feeding value of tropical pastures, 'Tropical Pastures', pp. 106-14. Ed. W. Davies and C. L. Skidmore. Faber and Faber, London.
Mitchell, K. J. (1966)—*N.Z. agric. Sci.* **2:** 23-9.
Morley, F. H. W. (1961)—*Adv. Agron.* **13:** 57-123.
Morley, F. H. W., Brock, R. D., and Davern, C. I. (1956)—*Aust. J. biol. Sci.* **9:** 1-17.
Munns, D. N. (1965)—*Aust. J. agric. Res.* **16:** 743-55.
Norman, M. J. T. (1962)—*Aust. J. exp. Agric. Anim. Husb.* **2:** 221-7.
Norman, M. J. T., and Arndt, W. (1959)—Performance of beef cattle on native and sown pasture at Katherine, N. T., Tech. paper No. 4. Div. Land Res. Reg. Surv. C.S.I.R.O.
Norris, D. O. (1958)—*Aust. J. agric. Res.* **9:** 629-32.
Nutrient Requirements of Domestic Animals (Heading for all bulletins). IV. Nutrient requirements of Beef Cattle. Publication 1137 National Academy of Sciences, National Research Council, Washington, D. C. 1963. V. Nutrient requirements of Sheep. Publication 1193 National Academy of Sciences, National Research Council, Washington, D. C. 1964.
Patil, B. D., Singh, S. V., and Singh, O. N. (1967)—*Indian Farming* **17:** 36-7.
Peak, J. W., and Morley, F. H. W. (1963)—Howard subterranean clover. Field Sta. Record Div. Pl. Ind. C.S.I.R.O. Aust. **2(1):** 45-6.
Pritchard, A. J., and Wutoh, J. G. (1964)—*Nature* **202**(4929): 322.
Riceman, D. S. (1945)—*J. Coun. Sci. Ind. Res. Aust.* **18:** 336-48.
Ritson, J. B. (1967)—Performance of cattle on Townsville lucerne-spear grass pastures. Rep. Div. Trop. Past. C.S.I.R.O., pp. 101-6.
Rossiter, R. C. (1964)—*Aust. J. agric. Res.* **15:** 61-76.
Schinckel, P. G. (1960)—*Aust. J. agric. Res.* **11:** 585-94.
Shaw, N. H. (1961)—*Aust. J. exp. Agric. Anim. Husb.* **1:** 73-80.
Simon, J. P. (1965*a*)—*Aust. J. agric. Res.* **16:** 31-6.
Simon, J. P. (1965*b*)—*Aust. J. agric. Res.* **16:** 51-60.
Simon, J. P. and Millington, A. J. (1967)—*Aust. J. Bot.* **15:** 35-73.
Teakle, L. J. H., and Stewart, A. M. (1939)—*J. Aust. Inst. agric. Sci.* **5:** 50-3.
Underwood, E. J. (1967)—*Agric. Gaz. New South Wales* **78:** 258-69.
Willoughby, W. M. (1954)—*Aust. J. agric. Res.* **5:** 157-80.
Willoughby, W. M. (1959)—*Aust. J. agric. Res.* **10:** 248-68.
Wutoh, J. G., Hutton, E. M., and Pritchard, A. J. (1968*a*)—*Aust. J. agric. Res.* **19:** 411-18.
Wutoh, J. G., Hutton, E. M., and Pritchard, A. J. (1968*b*)—*Aust. J. exp. Agric. Anim. Husb.* (In press).