AGRONOMIC FACTORS IN PASTURE AND FORAGE CROPS PRODUCTION IN TROPICAL AUSTRALIA

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INTRODUCTION

Limitations to pasture and crop production are imposed by many factors which operate in combination. Some of these factors cannot be modified with our present knowledge, e.g. temperature and day length fluctuations, radiation receipt and rainfall except for the use of irrigation. Others such as soil fertility, species composition and defoliation can be drastically modified to give increased output of pasture or fodder crops. However, the responses to modification in this way are limited, often to a considerable degree, by the factors which cannot be modified.

In this review we concentrate on the factors which are readily modified by man to influence the quantity and the quality of pastures and fodder crops.

Although the species used can greatly influence both quantity and quality of feed produced it is assumed that within any particular area adapted species will be used.

The importance of the various factors manipulated by the farmer may differ at different stages of growth of the pasture or crop. For convenience we have considered the effects of these factors on the establishment phase separately from those on the established pasture, and specifically as they relate to the dairying areas of tropical and subtropical Australia. For convenience, reference to the tropics also implies the sub-tropics where most of the published work in this field has been done.

ESTABLISHMENT PHASE

Seedbed preparation

Complete cultivation

Complete cultivation for seedbed preparation can affect crop or pasture emergence and growth through the resultant seedbed, subsoil storage of moisture, weed control, soil physical condition and soil fertility (Swain 1968; Carter and Saunders 1969). However, there is little information on the relative importance of these different aspects of cultivation on pasture and fodder crop establishment in the tropics except for the black earths of the Queensland Darling Downs where the effect of cultivation on both available nitrogen and moisture storage has been documented (Martin and Cox 1956).

Many seedbed preparation practices such as rolling and pre-cropping (Gartner and Fisher 1966; Ostrowski 1969a) have been recommended on the basis of local experience but no relevant experimental data have been published. One clearly defined problem is that of seedling emergence on self-mulching soils (Leslie 1965, 1968; Rickert 1970).

Oversowing

Although most experimental and farm pastures have been sown on cultivated seedbeds, there has been more research in the tropics into pasture establishment with minimal cultivation than on establishment with complete cultivation. Swain

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(1968) noted the generally unfavourable results from over-sowing and the general lack of understanding of factors involved in over-sowing. This is especially so for tropical species where there have been no studies to parallel the detailed laboratory and field studies made on temperate species in New South Wales (e.g. McWilliam and Dowling 1970; Campbell 1968).

Successful over-sowing of tropical species into existing tropical pasture treated only by burning or defoliation has been reported for siratro (*Phaseolus atropurpureus*) and stylo (*Stylosanthes guyanensis*) (Douglas 1965) and lotononis (*Lotononis bainesii*) (Roe, unpublished). Luck and Douglas (1965) successfully established siratro and glycine (*Glycine wightii*) with either minimal cultivation or herbicide treatment into mat grass although siratro performed better under adverse seedbed conditions than did glycine. Murtagh (1963) successfully established glycine into grass pasture by using a herbicide, but obtained poor results with rough cultivation or sod-seeding without a herbicide (Murtagh 1967).

Under good rainfall conditions the seedbed preparation may be less important than under dry conditions where burying the seed coupled with rolling has given better results than surface seeding (Tothill 1970). The desirability of using efficient sowing machinery for the oversowing of tropical pastures has also been stressed by O'Brien (1968).

Research has consequently shown that over-sowing of tropical species into summer growing pastures can be successful, but there is little information about the reliability of this practice. Over-sowing of summer germinating species into summer growing pasture is unavoidably breaking one of the rules for successful sod seeding (Grimmett 1967) in that the optimum times for germination of the sown species and for growth of the existing sward overlap. More success would be expected with the introduction of temperate species into summer swards, e.g. sub-clover (*Trifolium subterraneum*), (Murtagh, Mears and Swain 1964) and *Medicago* sp. (Roe *et al.* 1967, Cull and Norton 1966).

Successful sod-seeding of oats (*Avena sativa*) (Colman 1966a; Crofts, Laing and Kelleher 1970) and vetch (*Vicia* sp) (Colman, Swain and Holder 1965; Macadam 1968) into summer growing pastures has been achieved and farm acreage of oversown oats has increased in Queensland under irrigation (Anon 1970a). However, there are no experimental data on the reliability from year to year of sod-sown oats in dryland summer pasture. The low probabilities of receiving sufficient cool season rain for sod-seeded oats in the sub-tropics (Wheeler and Campbell 1969) may be partly compensated for by residual soil moisture storage.

Establishment fertilizer

The fertilizer requirements of establishing pasture have been measured for many areas of tropical and sub-tropical Australia (e.g. Colman 1964a, Ostrowski 1969b, Teitzel 1969, Kerridge 1970). These studies have consistently emphasised the need for phosphate and the less frequent responses to potassium, molybdenum and other nutrients. The need for fertilization at establishment is consequently emphasised in recommendations to farmers (e.g. Ostrowski 1969a; Middleton 1969). The need for lime to assist persistence of temperate legumes in some acid soils has been noted by Douglas (1962) and Roe and Jones (1966).

There has been less recognition of the effect of fertilizer usage and placement on the grass, legume and weed component of establishing pastures. Mears and Barkus (1970) noted that correction of phosphate deficiency when sowing pasture on a high nitrogen krasnozem lead to grass dominance in a mixed pasture. Similar trends were noted by Jamieson (1969) and Blunt and Humphreys (1970). Contrasted with this, when pastures are sown on nitrogen deficient soils, legumes are often dominant in the first years after sowing (Evans 1967, Mears 1968). The effect of soil nitrogen on botanical composition can be even more important if there is appreciable weed growth (authors' unpublished data). There is no published evidence from field experiments to support the recommendations (Anon 1970b) for use of fertilizer nitrogen when establishing grass-legume pastures.

Differences in fertilzer requirements for sown pastures and also in physical condition and weed population could be expected between old cultivation land, grassland and virgin forest or scrub.

Legume inoculation

The principles and practices for inoculation of tropical pastures have been laid down by Cloonan (1964) and Norris (1967).

Nodulation failures have been encountered with *Dolichos lab lab* and cowpea (*Vigna sinensis*) (Cloonan and Vincent 1967). However, late sowings and high levels of inoculum mitigated against failure. Philpotts (1970) suggested that deeper sowing and increasing surface cover would also assist nodulation in cowpea. Diatloff (1967) suggested that poor bacterial survival was responsible for failure of soybean to nodulate on black earths and not high soil nitrate level. *Glycine wightii* has been noted as slow and erratic to nodulate (Cloonan 1964; Diatloff and Ferguson 1970). *Trifolium semipilosum* has also been slow to establish (authors' unpublished data) and this may be partly a nodulation problem ('t Mannetje 1964).

Insect problems with bean fly (*Melanagromyza phaseoli*), Amnemus weevil (*Amnemus* sp.) and seed-harvesting ants have lead to studies of the effect of seed-applied insecticides on nodulation. Generally bean fly and Amnemus weevil can be controlled without detriment to nodulation although crown nodulation is sometimes reduced (Braithwaite, Gilbert and Jane 1965; Jones 1965; Russell and Coaldrake 1966; Diatloff 1970).

Species selection for establishment

Differences between temperate species in ease of establishment have been recorded by Roe (1958). Similar differences have been observed in at least some tropical species in both emergence and seedling growth. Consequently species, as well as being selected for climatic and edaphic suitability, can be selected for ease of establishment. This may be partly associated with seed size. Siratro, for example, averaged 61% emergence of readily viable seed on nine sowings on prepared seed beds, whereas greenleaf desmodium (*Desmodium intortum* cv. Greenleaf) sown at the same time averaged 32% (authors' unpublished data). Furthermore, the small desmodium seedings were more susceptible to death from grubs, deposition of soil wash and competition from weeds. Siratro has also established better than some other legumes when oversown on unprepared seedbeds (Douglas 1965; Luck and Douglas 1966; O'Brien 1968; Coaldrake and Russell 1969), Siratro also nodulates readily from applied or, in many cases, native rhizobia (Norris 1967) and can cope with heavy weed growth during establishment (R. M. Jones 1970b).

Selection of species for ease of establishment also implies that appropriate seed treatments are applied to maximize germination percentage and rate of emergence (Strickland 1971).

Time of sowing and seed rates

The months of sowing have been shown to be critical for establishment of irrigated pastures based on temperate species in south-east Queensland (Greasley 1962). Comparing sowing in February, April, June and September, Greasley found that April and June gave the best establishment and also the least weed. Furthermore, the time of sowing affected the subsequent botanical composition of the pasture. Whiteman and Lulham (1970) suggested that December was the optimum time of planting for tropical legumes at Samford, south-east Queensland, rather than October, February or March. However, the comparison was only made in one season and legume density was not measured.

Sowing time can also have implications in assisting emergence in self mulching soils (Leslie 1968), in reducing mortality from frosting in the first winter after sowing (R. M. Jones 1969) and in assisting nodulation (Cloonan and Vincent 1967). Laboratory studies on glycine by Murtagh (1970) imply that sowing of this species should be avoided when high soil temperatures can be expected. These findings remonstrate that the "best" time of sowing will depend on many factors such as soil type, rainfall and temperature regimes, sown species and weed competition.

Sowing rates of tropical legumes and grasses have been studied by Jones (1966b), Tow (1967a) and Middleton (1970). Generally increased legume seeding rates, or enhanced legume seedling survival (Tow 1967a), increased the legume component of the pasture. Increasing grass seeding rate decreased the legume component. However, it does not seem that changing seeding rates within the ranges usually recommended (Anon 1970b) will be a vital factor in determining pasture success or failure. The varying siratro rates sown by Jones (1966b) have since been subjected to two different grazing pressures. Heavy grazing pressure virtually eliminated the effect of seeding rate, although a small effect of seeding rate remained at the lighter grazing pressure (Jones 1968). Under very dry conditions at Biloela, Queensland, both green panic (*Panicum maximum* var. *trichoglume* cv. Petrie) and glycine survived as only sparse stands two years after sowing, regardless of initial seeding rate (Cameron and Courtice 1969).

The importance of high plant numbers in the establishment year will be less with cultivars that have good ability to spread, either by seed (e.g. green panic), or vegetatively (e.g. kikuyu (*Pennisetum clandestinum*) than with those which do not spread (e.g. lucerne (*Medicago sativa*)). Grazing management to allow a species to seed, particularly in the first year, will obviously facilitate its spread. The grazing management to achieve this end may differ between species, e.g. white clover (*Trifolium repens*) and siratro.

Planting schedules for forage crops are usually planned to give continuity of feed by selecting appropriate varieties (French 1969; Douglas 1970). Recommendations are available for sowing rates and row spacings (Anon 1970b).

Weed competition

There is little experimental data about the control of weed competition in establishing pastures, although extension publications suggest topping or strategic grazing (Ebersohn 1969; Ostrowski 1969a). Middleton (1970) found that pasture sowing rates did not affect weed growth in the first five months after sowing. In another experiment (R. M. Jones 1970b) pasture seeding rates had little effect on vigorous weed growth in the first four months after sowing whereas growth of pasture species was drastically reduced by weeds. Current results indicate that such weed growth had much less effect on pasture growth in the year after sowing. However, in a survey on the North Coast of New South Wales farmers did not specifically comment on weed problems in establishment of improved pasture (Auld 1971).

Studies in pre and post emergence use of weedicides in tropical pastures have shown a widely different reaction to 2,4-D (Bailey 1964, 1965, 1969). Siratro was very susceptible to 2,4-D and stylo very resistant. Greenleaf and silverleaf desmodium (*Desmodium uncinatum* cv. Silverleaf) had good tolerance and glycine intermediate tolerance. The value of weed control in establishing *Leucaena leucocephala* was demonstrated by Shaw (1965). Hand weeded plots yielded 3680 kg/ha of legume, plots with optimum herbicide application yielded 2770 kg/ha and control plots 49 kg/ha.

There has been less research into control of weeds in fodder crops than in grain crops, presumably due in part to the fact that many serious weeds in grain crops (e.g. wild oats (*Avena* sp.), Watkins 1970) present no problems in fodder crops. Most papers on fodder crops recognise few weed problems, and infer that 2,4-D or MCPA give suitable control where required (Douglas 1970).

PRODUCTIVE PHASE

Maintenance fertilizer requirements

Pastures on most soils require continued inputs of fertilizer if they are to resist invasion by undesirable species and remain productive. This has been assumed in most pasture studies. Annual rates of 125-500 kg/ha of superphosphate and 62-250 kg/ha of potassium chloride have been used on experimental pastures (Bryan and Sharpe 1965; Mears, Barkus and Moore 1966; Jones, Davies and Waite 1967; Bryan 1968; Evans 1969) and similar or lower recommendations have been made in extension publications (Ostrowski 1969a, Humphreys 1969, Teitzel and Bruce 1970). Few of these rates have been based on critical experimental evidence.

On the basis of a four year study of a siratro/*Setaria sphacelata* cv. Nandi pasture on a phyllite soil Jones (1966) suggested the use of 375 kg/ha superphosphate and 187 kg/ha of potassium chloride annually following a basal dressing of 750 kg/ha superphosphate. Lower dressings resulted in lower legume percentages and dry matter yields. However, a *Lotononis bainesii* setaria pasture on a latosol with a similar initial phosphate response (White and Haydock 1968) and basal superphosphate dressing showed little response to annual dressings of superphosphate (Jones 1966). At Beerwah, on the Wallum, lower beef production from improved pastures resulted from using half of the recommended maintenance dressing (125 kg super phosphate/ha instead of 250 kg/ha) but the reasons for this are not clearly known (Bryan personal communication). Both phosphorus and sulphur may be implicated and associated changes in yield, chemical composition and botanical composition.

At high nitrogen rates (400 kg/ha/annum) double the maintenance recommendations of phosphorus and potassium have been used in grazing studies (Evans 1969), but there is no evidence to suggest that they are necessary other than from plot experiments involving total removal of herbage (Gartner 1969b). On black earths in south-east Queensland the prime requirement for maintenance is sulphur, and annual dressings of 22 kg/ha/annum have been recommended to correct the deficiency in lucerne, the most important pasture species on these soils (Littler and Price 1967, R. M. Jones 1970a).

Of the trace elements only molybdenum has been demonstrated to require re-application on a regular basis to maintain production. On a krasnozem in N.S.W. Swain (1959) reported a large response three years after the initial dressing of 280 g of sodium molybdate/ha and 't Mannetje, Shaw and Elich (1963), on the basis of pot experiments, demonstrated the need for reapplication of the original dressing of 140 g/ha sodium molybdate every 3 to 4 years on a prairie-like soil from a drier site in central coastal Queensland. In addition to differences between soils in molybdenum fixation, and the possibility of leaching on wetter sites (Newman 1961), there is evidence that some species may require greater or more frequent applications (Luck and Douglas 1966).

Only on the wet heath soils of the Wallum have re-applications of lime, and the trace elements copper and zinc been found necessary (Young and Chippendale 1970). Such applications are necessary at least every five years, the lime being required to maintain pH at a level to support white clover. On the better drained Wallum re-application of these nutrients has not been found necessary although no critical evidence is available.

The impracticability of conducting field experiments on a sufficiently detailed scale to cover all soil types has led to the development of soil and plant analyses to aid recommendations for maintenance dressings. These have been discussed by Williams and Andrew (1970). For white clover and some of the tropical species Andrew (1968) has determined critical values which should greatly aid the intelligent use of annual topdressings for the maintenance of productivity. On specific soils the accumulation of research and extension experience can aid the assessment of fertilizer maintenance requirement, particularly phosphorus, but there is a very real place for fertilizer test strips on the farm, especially for the nutrients sulphur, potassium and molybdenum. Plant analysis is, however, the technique best suited to detect excessive use of specific fertilizers.

The use of nitrogen fertilizer

The recently realised potential of nitrogen fertilizer for providing out-of-season feed is clearly seen by comparison of the Wollongbar feed years suggested by Hudson *et al.* (1965) and Swain *et al.* (1970). Nitrogen, which was not used in 1965, has become the basis for out of season production of feed in 1970.

This change is partly attributable to the reliability of nitrogen in increasing yields of both dry matter and protein. Mean dry matter responses of 18-40 kg/kg nitrogen have been achieved in most studies with native species ('t Mannetje and Shaw 1972), naturalized species (Hegarty 1958; Henzell 1963; Colman 1963; Gartner 1969; Colman 1966b; Cassidy 1971), and sown species (Henzell 1963; Bryan and Sharpe 1965; Jones 1965b; Gartner 1967; Colman 1970). With grass-legume mixtures lower responses to nitrogen have been obtained as may be expected (Kleinschmidt 1967; Jones, Davies and Waite 1969; R. J. Jones 1970), but because of the slow growth of tropical legumes in spring, out of season yields of the mixtures may be increased (R. J. Jones 1970, Colman 1970).

Lower responses in terms of dry matter produced per unit of nitrogen applied, have been recorded in autumn, winter and early spring compared with those achieved in summer. Values for Kikuyu grass (*Pennisetum clandestinum*) measured by Colman (1966) over a 12 month period varied from 2.6 kg dry matter/kg nitrogen in June to 24.4 in February when the nitrogen was applied at a rate of 112 kg/ha every six weeks. Corresponding growth rates were 12 and 97 kg dry matter/ha/day for June and February.

Continued growth of the fertilized pastures in dry periods has been noted by Colman (1966b) and also by Henzell and Stirk (1963) who claimed that in south-east Queensland nitrogen and not water was usually the major limiting factor in tropical grass growth.

The low residual effect of nitrogen measured in most experiments necessitates re-application of the same rate each year if production is to be maintained. Methods of applying the annual nitrogen dressings to maintain pasture production have not been extensively studied in tropical Australia. From overseas results splitting the nitrogen dressing has had little effect on total dry matter yield compared with applying the same amount in a single dressing, except at heavy application rates or in very wet seasons (Henzell 1962). However, the effect on seasonal yield distribution could have very important consequences in animal production. Thus Evans (1970) has shown that frequency and rate of nitrogen application on a set stocked pangola grass pasture had marked effects on nitrogen content and dry matter yield on offer to the animals. Furthermore, applying the nitrogen in five or six applications gave higher liveweight gains than the same dressing applied in three or four applications. There is very little experimental evidence on which to base recommendations for devising the most appropriate combinations of size and number of dressings in any given situation. Since this is an agronomic technique entirely within the control of the farmer further research work on this important aspect is necessary.

Of the sources of nitrogen available urea seems to be the least efficient when compared on the basis of protein production (Henzell 1968, Colman 1970), but does not acidify the soil to the same extent as sulphate of ammonia.

In addition to the increased yields from nitrogen fertilization, favourable changes in the botanical composition of naturalized pastures have been reported by Gartner (1969a) where the low producing, low quality *Axonopus affinis* was replaced by Kikuyu grass. In south-east Queensland adding nitrogen or phosphorus to mat grass-paspalum pasture caused slower changes in the botanical composition (Cassidy 1971).

De Wit, Tow and Ennik (1966) reported a stimulation of glycine by adding nitrogen to a green panic-glycine mixture in pots, and Tow (1967b) has since suggested that nitrogen may be used to stimulate glycine growth after heavy grazing. Other workers have reported adverse effects on the tropical legume component from additions of nitrogen (R. J. Jones 1967a, 1970; Colman 1970) and at high rates (336 kg/ha/year) tropical legumes were eliminated (Jones, Davies and Waite 1969). Lower rates of nitrogen (112 kg/ha/year) applied out of season had little effect on legume yield in the first year of application but reduced legume yields subsequently (R. J. Jones 1970). It may therefore be possible to use nitrogen straegically on legume based pastures to produce out of season feed without serious harm to the legume, provided the nitrogen dressings are not repeated on the same paddocks every year. With irrigated pastures the adverse effect of nitrogen on the legume component has been far less pronounced (Kleinschmidt 1967; Jones *et al.* 1968) and the yield responses to nitrogen were lower than those reported for dry land pastures.

Unlike pastures, where the nitrogen response is predictable due to low mineralized nitrogen beneath grass swards, the response by fodder crops is less clear cut. Inherent soil fertility, length of fallow and climate will all affect the nitrogen availability and hence the response to applied nitrogen. Such parameters have been used to predict nitrogen fertilizer usage in grain crops (Leslie and Hart 1967) but similar predictions for forage crops have not been published. Large responses from nitrogen applied to oats at planting have been obtained at the first grazing, but there was no response in second growth from pre-sowing fertilizer applications of 29 kg nitrogen/ha (Cull and Muir 1969). Top dressings of 47 kg nitrogen/ha after the first grazing doubled regrowth dry matter yields and increased protein content (Cull and Douglas, personal communication). Similar recommendations for top dressing of oats are given by Wentholt (1968) and Appleyard (1967). Comparison of the nitrogen response of sod-seeded oats (Colman 1966a) with that of oats sown on a cultivated seed-bed (Cull and Muir 1969), suggests the latter may have a lower nitrogen requirement to maximize growth. The good responses of 30 kg dry matter/kg nitrogen with low rates of fertilizer from oats grown on cultivated seedbeds (Cull and Muir 1969) are far higher than those achieved with similar dressings on permanent pasture (Henzell 1963).

Surprisingly little information is published for the responses of summer fodder crops to nitrogen top dressings. On fallowed land the high summer temperatures may at times result in adequate mineralization of soil nitrogen for crop growth and excess nitrogen may result in lodged crops (Douglas 1970). On most sites, however, responses to nitrogen would be expected, certainly on regrowths.

Species

Continued production depends also upon the species composition of the pastures. In the absence of a persistent legume, pastures can deteriorate rapidly even with adequate non-nitrogenous fertilizer use. Some legumes are short lived or fail to regenerate satisfactorily in pastures, e.g. *Vigna luteola* (Jones, Davies and Waite 1967) and *Phaseolus lathyroides* (R. J. Jones 1966a; 1970) give little lasting benefit to the pastures and could initially reduce the productivity of associated perennial legumes (R. J. Jones 1970). Among the truly perennial species some appear to be more persistent than others (Douglas 1965; Jones, Davies and Waite 1967; Middleton 1969; Coaldrake and Russell 1969). For example *Desmodium intortum* is susceptible to dry periods in otherwise reliable rainfall areas (Roe, Jones and Rees 1970) and glycine is less suited to wetter podsolic or gleyed soils than siratro or desmodium (Kyneur 1963; Murtagh, Mears and Swain 1964).

An appreciation of the differences in yield and quality which occur between species and cultivars and resistance to diseases, pests, waterlogging, drought, soil type, fire, frost and grazing (Davies and Hutton 1970) will result in pastures with higher quality, greater persistence, productivity and ease of management. Differences in seasonal production could be of far more importance than overall dry matter yield in the assessment of the species. For example, under frosty conditions in south-east Queensland *Setaria sphacelata* CPI 33452 has shown better persistence, higher winter/spring yields and higher digestibility than Nandi setaria (Roe, Jones and Rees 1970, Hacker and Jones 1969).

Selection of fodder crop cultivars will mainly depend on climate, soil type and seasonal requirements for grazing. Disease resistant strains, e.g. Caloona cowpea (Purss 1963), will have obvious advantages, and the use of different cultivars of fodder crop can assist in continuity of production (French 1969). A recommended feed year for Darling Downs dairy farmers illustrates how appropriate winter and summer fodder crop cultivars can be integrated with pasture (Howard and Cull, personal communication).

Many temperate legumes have been grown successfully at times in the sub-tropics—white clover, vetch, sub-clover (Murtagh, Mears and Swain 1964); lucerne, annual medics (Russell 1969; Roe, Jones and Rees 1970). However, the reliability of these species within the dairying feed year has been questioned (Colman, Holder and Swain 1966). This is partly due to rainfall variability and partly to the serious effect of diseases and pests (Colman 1964b; Braithwaite 1959; Allen 1965). Greater damage from diseases and pests could be expected when temperate legumes are grown away from temperate environments.

Temperate perennial grasses have had limited success in irrigated pastures. Under dryland conditions temperate perennial grasses in the 30 in. (760 mm) rainfall zone in south-east Queensland have usually shown poorer persistence than tropical grasses (Jones and Rees, unpublished).

There is no apparent advantage in using a mixture of grasses as compared with the most suitable species used alone (Jones, Davies and Waite 1969). No such studies with mixtures of legumes have been published and management problems may be considerably complicated with certain mixtures, e.g. lucerne and glycine (Santhirasegaram, Coaldrake and Salih 1966).

Grazing management

Although recommendations for grazing management have been given in extension publications (Douglas and Luck 1964, Ebersohn 1969, Ostrowski 1969a) there is very little experimental data on the effects of grazing management on the production, changes in botanical composition and persistence of the pasture species used in tropical Australia. A major objective in the grazing management must be to maintain the tropical legume component.

Management practices to achieve this may be quite different from those developed for temperate legume pastures and it seems clear that repeated close defoliation of perennial twining tropical legumes may lead to reduced vigour and death with consequent decline in pasture productivity (Santhirasegaram, Coaldrake and Salih 1966; Jones 1967a; Whiteman 1969). With the non-twining, lower growing *Lotononis bainesii* continued frequent cutting had no permanent adverse effect on yielding ability but cutting every four weeks gave lower yields than cutting every eight or 12 weeks (Bryan, Sharpe and Haydock 1971). In the presence of Rhodes grass (*Chloris gayana*) however, *L. bainesii* failed to persist under frequent close cutting or grazing with sheep (Whiteman 1969).

One report suggests that heavy rather than lenient cutting or grazing may be necessary to achieve maximum utilization from the tropical legumes (Young and Robinson 1963), and another that variations in cutting frequency and cutting height had little effect on the yield of *Desmodium intortum* (Riveros and Wilson 1970). These results, achieved with no moisture restriction, are at variance with practical experience, extension publications (Douglas and Luck 1964) references previously cited and overseas results with these legumes.

Although the decline in yield of grasses with increasing frequency of cutting is also well documented (Shaw *et al.* 1965; Bryan and Sharpe 1965), the decline in the tropical legume component of mixtures is greater than that of the grass (Jones 1967a; Whiteman 1969) and is associated with reduction in nodule numbers per plant (Whiteman 1970).

Humphreys (1966) has emphasised the complexity of the interacting factors which govern the reaction of grasses to defoliation. Consequently simple grazing practices to increase pasture production may not be easy to achieve under practical management conditions.

No data for tropical species have been published comparable to that of Campbell (1969) in New Zealand on the relative yields of pastures set stocked or rotationally grazed at different stocking rates. Therefore arguments concerning the relative merits of the methods are purely speculative at the moment—at least as far as pasture productivity and persistence are concerned. Management of temperate species in the tropics has followed traditional methods, and advice on management of white clover swards involves slashing or grazing to control grass growth in summer and the need for rotational grazing (e.g. Ebersohn 1969).

From the practical point of view the farmer is faced with the need to feed a relatively fixed number of cows with a fluctuating supply of feed. At times the need to feed the cows may conflict with the need to manage the pastures properly and the pastures may suffer. There is little information to enable the farmer to predict the outcome of mismanagement or even to describe accurately what constitutes good management—particularly for tropical species.

Management may also be designed for purposes other than providing immediate feed for stock, e.g. for the control of regrowth and weeds. Under these conditions lax grazing or the exclusion of grazing will utilize the smothering capacity of the twining tropical legumes (Tutt and Luck 1969; Auld 1971). In some situations, however, heavier stocking could be employed to aid in the control of regrowth of tree and shrub species.

With annual forage crops persistence need not be considered in the grazing management. Usually the crops are grown for specific purposes and can be eaten off at the optimum time to ensure satisfactory regrowth and high quality feed. Utilization to achieve both high yields and minimum wastage are prime requirements. Grazing to maintain the crop in the vegetative stage has been advocated (French 1969). Total yields may well be reduced by such management (Pritchard

1971) but there are few published results of quantitative studies relating management to yields and quality of these fodder crops. Utilizing forage sorghums by grazing at high stocking rate for a short period (3 steers/ha for 63 days) gave gains of 0.8 to 1.1 kg/head/day which was similar to gains obtained by grazing at half this stocking rate for 126 days (French 1970). The importance of trampling losses with grazed oats has been highlighted by Smith (1970). Under continuous grazing at 3.6 and 6.0 beasts/ha he estimated losses to be about 40%. It is conceivable that strip grazing could have reduced this loss but there are no published results to this effect.

The importance of managing *Dolichos lab lab* so as to maintain maximum leaf production throughout the growing period has been noted by Murtagh and Dougherty (1968) and Hamilton (1969). The recommended rotational grazing for lucerne in sub-tropical areas (Cameron 1968) is basically the same as for temperate areas (Moore, Barrie and Kipps 1946, Sheridan 1964).

Irrigation

Irrigated pastures in Queensland and northern New South Wales are based on white clover as the sown legume. A wide range of companion grasses has been experimentally examined. Jones *et al.* (1968) concluded that a summer grass was preferable as winter species failed to persist and were replaced by summer grasses such as Rhodes grass and *Paspalum dilatatum.* Kleinschmidt and Kent (1964) also noted the "weed" potential of these summer grasses in invading temperate grass pastures, but were further evaluating *Phalaris* and *Fescue* species. Resting *Phalaris tuberosa*/white clover pastures in summer maintained phalaris and reduced clover dominance (Kleinschmidt 1964). Cameron (1969) again found that stable white clover/paspalum (*Paspalum dilatatum*) pastures could be grown at Biloela, Queensland, although it is difficult to maintain temperate grasses in these pastures (Grof, Cameron and Courtice 1969; Cameron, Courtice and Mullaly 1969). Clearly it is very difficult to maintain temperate grasses in irrigated pasture even with optimum management. This need not detract from their value as a pasture component in the initial year or two after sowing.

Nitrogen increased dry matter yields of green panic, green panic/lucerne and green panic/glycine at Lawes, Queensland although there was no increase in nitrogen yield when nitrogen was applied to green panic/lucerne. Sod-seeded oats with nitrogen have been used successfully to assist in providing winter feed in irrigated pastures (Anon, 1970a; Crofts, Laing and Kelleher 1970), though without practical benefit by Kleinschmidt and Kent (1964). Irrigated oats are used for winter feed as far north as the Atherton tableland (Gartner 1965).

There is considerable dairy farmer interest in irrigated pastures as evidenced by the fact that in the Gympie area Rees and Minson (1970) found 75% of farmers had irrigated pasture. Out of all tropical and temperate species sown by farmers in this survey, white clover and H.I. rye grass had been sown by the greatest number of farmers. However, the economic advantages of irrigated pastures are dependent upon the farmers ability to achieve the potential production increase (Bird and Mason 1964). Henzell and Stirk (1963) found that, in most years, nitrogen was more limiting than water for spring growth of grass pastures. However, these results would not be applicable to white clover based pastures.

Fodder conservation

Much of the feed eaten by dairy cows in the winter is standover feed and has therefore been conserved *"in situ"*. Legumes in the unfrosted state are considered to provide a far better standover feed than mature grasses (Luck 1968), but under frosted conditions the tropical legumes can lose over 80% of their pre-winter yield of dry matter and protein and would then be a poorer feed than frosted grass (Jones 1967b; Whiteman 1968).

Fodder conservation of surplus summer feed has obvious advantages as a technique of filling gaps in the feed year. Forage crop hay has been recommended for coastal south-east Queensland (Hegarty 1953), but is little used (Rees, personal communication). This is doubtless partly due to the hazards of rain, but the risks of rain ruining hay have been decreased by advances in the mechanization of haymaking.

Silage is also rarely used in the Gympie area (Rees, personal communication) although increasing use was noted in the Atherton Tableland (Smith and Jamieson 1969). With increasing knowledge about the ensilage of tropical species (Catchpoole 1970) and increasing farm mechanization it is technically practicable to make silage from both surplus pasture and fodder crops.

The dairying feed year

Much of the research described in previous sections of this review has been partly or wholly directed at providing a reliable out of season supply of quality forage, i.e. the use of nitrogen, fodder crops, conservation, irrigation, temperate species and tropical species able to supply winter feed. It is not within the scope of this review to assess the problems involved in integrating these techniques.

THE FUTURE

The agronomic factors which influence pasture and fodder crop production in the dairying areas of the tropics can only operate within the prevailing climatic conditions. Relevant climatic data for these areas have been briefly summarised by Fitzpatrick and Nix (1970), and the main dairying areas described by Bryan (1970). Characteristic limiting factors for the growth of tropical species are unreliable spring rain, cool winter temperatures and, in many areas, frost.

Temperature cannot be controlled by the farmer and irrigation is only feasible on some properties. Hence the many attempts to provide winter and spring feed by use of agronomic techniques reviewed in this paper. The one alternative that would seem to have been inadequately examined is that of using conserved fodder, from the relatively highly reliable summer pasture growth, as the basis for out of season feeding. Not only is rainfall more reliable in the summer months but there is a relatively greater increase in pasture growth from summer nitrogen application than from out of season nitrogen. It is possible that further research into fodder conservation could make this a practicable approach to levelling out the feed year. This would basically involve research into better utilization of reliable rainfall, as distinct from present research into techniques for better utilization of unreliable rainfall.

We suggest that current work could be concentrated more on the following general lines—though this does not imply that knowledge is adequate in all other fields.

(1) There is insufficient information on the reliability of oversowing and minimal cultivation techniques for the establishment of pastures and forage crops. Further work would presumably involve both field experimentation and subsequent model building. Valid evaluation of these techniques can only be made when there is adequate knowledge of their residual effects on subsequent pasture or crop growth.

(2) There is inadequate understanding of the interacting factors operating on establishing pastures. Most work has been done on seed rates, possibly due to the relative ease with which such experiments can be carried out. The whole complex of interactions between factors such as soil nitrogen, fertilizer rate and placement, weed growth, topping and grazing has not been examined.

(3) Since fertilizer input is so essential to pasture productivity there is need to define the maintenance needs of pastures under grazing with plot studies and to relate responses to chemical analysis of the herbage, or fractions of the herbage, so that extrapolation to other pastures can be made with the aid of local knowledge.

(4) The relative performance of species over different soils, and on sites differing in moisture availability is inadequately known. Use of the Finlay and Wilkinson (1963) approach should help to define the performance of the species in a clearer way, as recently shown on the Atherton Tableland (Gartner *et al.* unpublished) and should also enable comparisons of mixtures of species with single species swards. There are no published data on the value of using mixtures of legumes although these are widely advocated. This in itself may be an admission of our lack of knowledge of species performance.

(5) There is no general guide for the use of nitrogen on fodder crops similar to that for grain crops (Leslie and Hart 1967), neither is there much information on the effect of grazing at different stages of forage crop growth on animal production, total yield of forage and utilization of this yield.

(6) There is inadequate knowledge of the management of tropical grass/tropical legume pastures and tropical grass/white clover pastures. The widely differing success with these pastures may partly be due to differences in management. Knowledge of what constitutes gross mismanagement is as important as knowledge of optimum management. Since these pastures may form the basis of dairying in the tropical areas of Australia the absence of reliable information on this aspect is a serious gap. Studies to define the responses to defoliation of individual species, as well as studies on mixtures grazed in different ways, are needed so that the outcome of management variables may be predicted. The increasing use of strategic nitrogen dressings on grass-legume pastures would indicate that further studies on the effect of such dressings on different grass-legume mixtures are warranted.

(7) Finally, the agronomic practices outlined eventually need to be evaluated on a "whole farm" basis to assess the feasibility and economics in a real farm situation (Wheeler and Campbell 1969). In this connection the economic surveys of the Wide Bay Area (Burns and Doumany 1963; Burns and Briggs 1964; Cassidy and Burns 1965; Tomes and Burns 1967) suggest that dry land tropical pastures offer the best economic approach to increasing milk production.

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