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QUANTITY OF PASTURE AND FORAGE CROPS FOR DAIRY PRODUCTION IN THE TROPICAL REGIONS OF AUSTRALIA

1. REVIEW OF THE LITERATURE

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INTRODUCTION

The amount of herbage produced by pastures and crops is determined by a complex of interacting factors, of which some can be controlled by man whilst others operate in seasonal cycles which are more-or-less predictable. The yield of a pasture is best measured in terms of animal product but this is costly and usually possible for only a few treatments. The traditional method of measuring herbage yield of pasture plants has been by mechanical harvesting during the growing season with either mowing or grazing following sampling. In this review quantity of herbage is defined as the amount measured by cutting in particular seasons or on a 12-month basis. The limitations to herbage production considered in this review are those related specifically to the growth of the plant and do not include management factors associated with utilization of the pasture or crop by dairy cattle.

The primary objective of the review will be to highlight the factors of production which are important in relation to tropical areas and to define the periods of most severe feed shortage. This will provide the basis for suggesting ways of overcoming the problem periods and defining research priorities.

ANNUAL FEED REQUIREMENTS OF THE DAIRY COW

In order to assess the likelihood of a pasture satisfying the feed requirements of a dairy cow, it is as well to provide some estimate of this requirement for a cow producing at a reasonable level of production and on feed with a range of feeding values. For a cow weighing 500 kg it has been estimated (Anon 1965) that the required dry matter intake of feed for the production of 10 kg milk daily plus maintenance varies from 2500 kg annually at a metabolisable energy content of 3.0 Mcal/kg to 5300 kg annually at a metabolisable energy of 1.8 Mcal/kg.

These intake values can only provide a basis for assessing the ability of a pasture to yield sufficient dry matter for an animal's requirements if it is assumed that the pasture produces feed as required by the animals and that pasture remaining in the field maintains its nutritive value. Neither of these assumptions can be made, so that annual pasture production would have to be in excess of requirements on an annual basis if the food needs of the animals being carried were to be satisfied.

HERBAGE YIELDS IN THE SUB-TROPICS AND TROPICS OF AUSTRALIA

The production of dry matter by pastures and forage crops has been measured for a large number of legumes and grasses in the region extending from north-eastern N.S.W. to far north-eastern coast of Queensland. Herbage yields are presented in four categories—a) tropical legume-grass pastures (Table 1), b) tropical grass pastures with nitrogen fertilizer (Table 2), c) temperate pastures (Table 3) and d) forage crops (Table 4). A summary of pasture yields is given in Table 5.

Most of the data presented come from cutting experiments although in many studies the yields are the sum of harvested pasture prior to grazing. Usually the yields represent the total dry matter of the pasture which includes such fractions as stem and flowering parts which are frequently rejected by the grazing animal.

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TABLE I

Dry matter yields of tropical legume-grass pastures in coastal and near coastal locations of northern New South Wales and Queensland.

Location	Species	Yields (kg/ha)	Comments
Richmond-Tweed Region, N.S.W.			
Murtagh and Mears (1964)	*Glycine wightii* cv. Clarence	530– 5,300 (4 sites)	Annual yields of legume from three cuts followed by grazing. Plots located on a range of soil types. *Desmodium* superior to *Glycine* on wetter sites. *Lotononis* not persistent when ungrazed.
Mears, Murtagh and Wilson (1964)	*Desmodium uncinatum* cv. Silverleaf	2,400– 5,470 (4 sites)	
	Lotononis bainesii cv. Miles	2,100– 3,600 (3 sites)	
	Phaseolus atropurpureus cv. Siratro	2,200– 5,300 (4 sites)	
	Desmodium intortum ex. Hawaii	6,470 (1 site)	
Mears, Murtagh and Swain (pers. comm.)	*Glycine wightii*	4,760	Mean of 56 paddock yields.
	plus grass	5,780	Mean of 23 plot yields.
Wollongbar, N.S.W.			
Colman, Holder and Swain (1966)	*Glycine wightii*-*Pennisetum clandestinum* (kikuyu)	7,700– 8,200	Legume content 34 to 60 per cent declined with age of pasture. January to May yields under rotational grazing with dairy cows.
Lawes, Qld.			
Edye (1967)	*Glycine wightii*	1,900– 4,100	Mean yields over five years under grazing. Range for 12 cultivars. Cooper variety highest yield.
	Panicum maximum var. *trichoglume*	4,500	
Samford, Qld.			
Hutton and Bonner (1960)	*Leucaena leucocephala* cv. Peru	12,600	Dry matter yield over 9 months contained 3,580 kg crude protein.
Hutton (1962)	*Phaseolus atropurpureus* cv. Siratro *Chloris gayana* cv. Commercial	8,800	Second season of growth—four cuts in spring, early summer, late summer and autumn.
Jones, Davies and Waite (1967)	*Lotononis bainesii*	1,100– 3,700 (legume) 8,400–13,700 (total pasture)	Range of annual yields over four years. Grass—*P. plicatulum* cv. Hartley.
	Phaseolus atropurpureus Breeders material	1,400– 3,800 (legume) 4,800–13,000 (total pasture)	Range of annual yields over five years.
Jones (1967)	*Phaseolus atropurpureus* Siratro	1,600– 7,300 (legume) 10,600 (total pasture)	Yields are the range for four weekly (lowest yield) to 16 weekly cuts.
	Medicago sativa Hunter River	5,300 (legume) 12,600 (total pasture)	Lucerne cut every four weeks.
		Uncut *Grazed*	
Whiteman (1969)	*Lotononis bainesii*	2,600 1,400	Legume yields—mean over two years. Grass yields approximately twice the legume. Proportion of legume declined under grazing
	Glycine wightii cv. Cooper	6,200 2,100	
	P. atropurpureus cv. Siratro	4,300 1,100	
	Desmodium uncinatum	7,100 400	
	*Trifolium repens** Naturalised	230 2,100	
Beerwah, Qld.			
Bryan (1961)	*Lotononis bainesii*	250– 1,900	Yields in summer—eight weeks between grazings.
	Digitaria decumbens Pangola grass	1,570– 2,350	
Bryan (1966)	*Desmodium intortum* cv. Greenleaf	600– 2,200 19-54% of pasture yield	Nursery plots grazed every 60 days. Associated with a range o tropical grasses on siliceous sands

TABLE 1 (continued)

Location	Species	Yields (kg/ha)	Comments
	Desmodium uncinatum cv. Silverleaf	34– 1,100 2-30% of pasture yield	Low yield during establishment year in drought. Persistent in pasture from 1957-1963 with 8 weekly grazing.
Howard, Qld. Evans (1967)	*P. atropurpureus* cv. Siratro	8,600	Legume yields in pure swards—means of three years except for *T. semipilosum* (1 year).
	L. bainesii cv. Miles	5,200	
	Glycine wightii CPI 27834	3,700	
	*Trifolium semipilosum** Kenya white clover	9,400	
Lansdown, Qld. Edye (1967)	*Glycine wightii*	1,040– 4,600 (legume)	Mean yields over three years for 26 cultivars. Tinaroo variety highest yield.
	Cenchrus *ciliaris* cv. Nunbank	5,400 (grass)	
South Johnstone, Qld. Grof and Harding (1970)	*Centrosema pubescens*	>11,200	Annual yields in pure swards. Introduction with improved winter production.

* Temperate species

TABLE 2

Dry matter yields of tropical grass pastures, some fertilized with nitrogen, in the sub-tropics and tropics of northern New South Wales and Queensland

Location	Species	Yields (kg/ha)	Comments
Wollongbar, N.S.W. Colman (1964)	*Paspalum dilatatum*	2,700–13,600	Annual yields from nil to 800 kg N/ha on red basaltic soil.
Colman (1965, 1966a)	*Pennisetum clandestinum* Kikuyu grass	8,700–30,900	Mean annual yields over two years with 6-weekly cutting. Nitrogen rates from nil to 1,120 kg N/ha.
	Digitaria decumbens	18,000–N 448	
	Setaria sphacelata cv. Kazungula	15,900–N 448	
Coraki, N.S.W. Colman (1964)	*P. dilatatum*	8,600–21,700	Annual yields from nil to 940 kg N/ha on alluvial soils (irrigated).
Samford, Qld. Henzell (1963)	*Chloris gayana* cv. Commercial	4,500–24,100	Nitrogen rate experiment. Annual yields—nil to 448 kg N/ha.
	Paspalum commersonii	6,200–20,200	
	P. dilatatum	3,900–21,300	
Bryan and Shaw (1964)	*P. plicatulum*		Annual yields over two years. Fertilized with 448 kg N/ha, 500 kg superphosphate and 250 kg potassium sulphate/ha/annum.
	cv. Rodd's Bay CPI 2741	22,100–27,700	
	cv. Hartley CPI 11826	19,100–20,800	
	P. dilatatum	11,800–15,700	
Shaw *et al.* (1965)	*Paspalum dilatatum*	12,100	Mean annual yields over two years. 448 kg N, 500 kg superphosphate and 250 kg potassium sulphate/ha/annum.
	P. notatum 9073	22,960	
	P. plicatulum 2741	21,300	
	P. yaguaronense	22,100	
Beerwah, Qld.		*Nitrogen Rate* — *Cutting Interval* 4 *Weeks* — 12 *Weeks*	
Bryan and Sharpe (1965)	*Digitaria decumbens* Pangola grass	112 — 3,600 — 13,300 336 — 8,400 — 20,900 560 — 11,200 — 24,200	Mean annual yields over two years.

TABLE 2 (continued)

Location	Species	Yields (kg/ha)	Comments
Howard, Qld. Evans (1967)	*Panicum coloratum* CPI 16796	23,000	Mean yields over three year Limited grazing in third yea Nitrogen fertilizer at 224 k N/ha/annum.
	Chloris gayana cv. Samford Rhodes	14,100	
	Setaria sphacelata cv. Nandi	10,600	
	Paspalum dilatatum	5,700	
Atherton, Qld. Gartner (1967)	*Panicum maximum* var. Trichoglume	6,200–10,000	Annual yields with nil and 158 k N/ha.
Gartner (1969)	*Pennisetum clandestinum*, *P. dilatatum* and *Axonopus affinis* mixture	1.700–12,200	Annual yields with nil to 448 k N/ha.

TABLE 3

Dry matter yields of temperate pasture species growing in the sub-tropics and tropics of northern New South Wales an Queensland

Location	Species	Yields (kg/ha)	Comments
Dunoon, N.S.W. Jenkins (1957)	*Trifolium subterraneum* cv. Clare	2,800	Second year growth from r generated seedlings—March September.
Richmond-Tweed, N.S.W. Mears, Murtagh and Swain (pers. comm.)		1,900	Mean of 14 paddock yields.
		2,210	Mean of 7 plot yields.
Boonah-Beaudesert, Qld. Roe, Jones and Rees (1970)	*T. subterraneum*		Sown May, 1968. Yields August 1969 following regener tion.
	cv. Clare	3,900	
	cv. Woogenellup	2,300	
	Medicago truncatula cv. Jemalong	3,600	
Samford, Qld. Jones *et al.* (1968)	Temperate pasture species invaded by *P. dilatatum.* White clover main legume.	17,800–N o 19,210–N 336	Irrigated when moisture defic exceeding 50 mm. Pastures graze following sampling. Grazing pre sure determined by yield. *Cent sema pubescens, L. bainesii* a *D. uncinatum* not persistent high grazing pressure.
	Temperate and tropical species—Samford Rhodes, *S. sphacelata* cv. Nandi, white clover	19,300–N o 23,800–N 336	
Roe, Jones and Rees (1970)	*Phalaris tuberosa* cv. Sirocco	9,700	Dry matter from July to Nove ber.
	Festuca arundinacea cv. Demeter	8,300	
	Bromus catharticus cv. Priebe	8,500	
	T. subterraneum		Yield from cuts in July a October.
	cv. Howard	6,000	
	cv. Clare	4,500	
	cv. Bacchus Marsh	3,500	
Conondale, Qld. Roe, Jones and Rees (1970)	*Setaria sphacelata*		Winter production — April October.
	CPI 33452	6,800	
	cv. Kazungula	4,400	
	Bromus catharticus cv. Priebe	780	
	Phalaris—hybrid	620	
Biloela, Qld. Grof, Cameron, and Courtice (1969)	*Trifolium repens* cv. Ladino	10,200–12,100 (legume)	Annual yields with irrigatio Means of three years. Bromus persistent.
	Bromus unioloides	3,400– 3,800 (grass)	

TABLE 4

Dry matter yields of summer and winter forage crops grown in the sub-tropics and tropics of northern New South Wales and Queensland

Location	Species	Yields (kg/ha)	Comments
Richmond-Tweed Region, N.S.W.			
Jenkins (1957)	*Vicia sativa* cv. Golden tares	Up to 8,000	Yields from planting to flowering (23 weeks). Yield considerably reduced by disease (Allen *et al.* 1969).
Holder, Swain and Colman (1963)		1,120– 3,100	Sod-sown into grass dominant pastures in autumn. Yield at a single grazing.
Mears, Murtagh and Swain (pers. comm.)		1,680 2,870	Mean of 65 paddock yields. Mean of 17 plot yields.
Murtagh and Dougherty (1968)	*Dolichos lablab* cv. Rongai	400– 2,200 (leaf)	Yields are for two growth periods with grazing in March.
	Stizolobium deeringianum Velvet bean	190– 1,500 (leaf)	
Richmond-Tweed Region, N.S.W. (continued)			
Murtagh (unpublished)	Oats var. Saia	3,000–10,700	Variety trials—3 to 4 harvests 112 kg N/ha. Range of yields in poor and good seasons.
	Klein 69B	4,100– 9,500	
	Cooba	2,770–10,200	
	Algerian	2,730–10,300	
	Oats var. Saia	3,300–N 0	Nitrogen rate trial on red basaltic soil. Fertile site.
		4,750–N 45	
		5,150–N 100	
Colman (1966b)	Oats	770–N 0	Sod-sown with anhydrous ammonia.
		1,700–N 67	
		3,300–N 134	
Mears, Murtagh and Swain (pers. comm.)	Oats plus N	2,317	Mean of 6 paddock yields.
		4,030	Mean of 6 plot yields.
Lawes, Qld.			
Pritchard (1964)	*Sorghum alum* and *S. sudanense* cultivars and hybrids	4,500–19,000	Nitrogen fertilizer up to 900 kg/ha. Yields are the range over three years; the highest value is for the Indian hybrid "Krish".
Biloela, Qld.			
Anon. (1960)	*Medicago sativa*	14,600	Mean yields over six years under irrigation. Lucerne maintained production throughout the year.
	Oats, field peas on vetch in winter; cowpeas on mung beans with *Setaria* in summer	7,300	
Biloela, Qld. (continued)			
Daday *et al.* (1968)	*Medicago sativa*		Yields from winter 1964 to January 1965.
	cv. Hunter River	7,600	
	cv. African	7,400	
	cv. Hairy Peruvian	8,300	

TABLE 5

Summary of pasture yields given in tables 1, 2 *and* 3. *Values are the means of the highest yields at each location*

Location	Tropical Legumes	Tropical Grasses	Temperate Species
Richmond-Tweed Region N.S.W	5,200 (a) 6,200 (b)	20,000	2,300
Boonah-Beaudesert, Qld.	—	—	3,250
Lawes, Qld.	4,100 (a) 8,600 (b)	—	—
Samford, Qld.	5,450 (a) 12,500 (b)	20,800	4,700 (a) 8,830 (c) 17,8000 (e)
Beerwah, Qld.	1,890 (a) 4,100 (b)	24,200	—
Howard, Qld.	6,700 (a)	13,300	—
Conondale, Qld.	—	—	700 (c) 6,800 (d)
Biloela, Qld.	—	—	12,100 (a, e) 3,800 (c, e)
Lansdown, Qld.	4,600 (a) 10,000 (b)	—	—
Atherton, Qld.	—	11,100	—
South Johnstone, Qld.	11,200 (a)	—	—

(a) Legume yield. (b) Legume-grass yield. (c) Grasses alone.
(d) Tropical grass ("winter" production). (e) Irrigated (Annual yield).

Tropical legume-grass pastures

The yield potential of tropical legume-grass pastures, especially in the higher tropical latitudes, and on the basis of data in Table 1, is much less than for temperate legume-grass pastures in south-eastern Australia or New Zealand. For example, well established ryegrass-white clover pastures in New Zealand have produced in excess of 15,000 kg/ha of dry matter annually and frequently yields have been in excess of 11,000 kg/ha even on soils of only moderate fertility (Sears 1953; Levy 1956). Much of the information presented in Table 1 is for the sub-tropics and it is possible that higher yields of tropical legume pastures may be obtained in the warmer and wetter northern tropics. For example, the highest yield of pure legume, with the exception of the shrub *Leucaena leucocephala,* was 11,200 kg/ha of *Centrosema pubescens* at South Johnstone, Queensland (Grof and Harding 1970) compared with 8000 to 9000 kg/ha for the highest yield of legume in south-east Queensland and Northern N.S.W. (Hutton 1962; Evans 1967).

The maintenance of high yield in a mixed pasture depends largely on the productivity of the legume. Little published information is available on the long term yields of tropical legume-grass pastures. Under grazing with dairy cows at Wollongbar, N.S.W. the total dry matter yields of a *Glycine wightii*-kikuyu grass pasture from early spring to autumn were 8150, 7700, 7700, 9400 and 8200 kg/ha in the years 1962/63 to 1966/67. The proportion of legume declined from 60% in 1962/63 to 33% in 1964/65 and 26% in 1966/67. Stocking rate on the pasture was increased from 1.23 to 1.85 cows/ha over the 5 year period but was low in the establishment year (Colman, Holder and Swain 1966; Colman, unpublished data). Although pasture yield was not determined after 1966/67 grazing was continued as part of grazing experiments (Jeffery *et al.* 1970) until 1967/68 when the proportion of glycine had declined to a low level. Instability of the legume could be attributed to increased grazing pressure resulting from the high stocking rate and the occurrence of drought. On the basis of total yields in Table 1 it can be concluded that a satisfactory tropical legume grass pasture can produce sufficient feed for 1½ cows/ha if the feed is utilized efficiently.

Tropical grasses

It is generally accepted that the ceiling yield of pasture grasses in the tropics exceeds that of the temperate grasses in cool climate regions. Cooper (1970) recorded the results of experiments in a range of environments in which grass production was measured with high levels of applied nitrogen. Under temperate conditions yields of *Lolium perenne* and *Dactylis glomerata* were in the range of 16,700 to 26,600 kg/ha/year. In the sub-tropics, including south-east Queensland and north-eastern N.S.W., dry matter production ranged from 20,100 to 31,900 kg/ha/year and in the tropics the values were 29,900 to 84,700 kg/ha/year for a range of warm climate grasses. Thus, for northern N.S.W. and Queensland the potential production of tropical grass plus nitrogen is at least twice that of a tropical legume grass pasture in the same environment or a temperate pasture in the cool climate dairying areas. With yields of 15,000 to 20,000 kg of dry matter/ha and 80 to 90% utilization, sufficient feed can be produced on each hectare to satisfy the annual requirements of at least 3½ cows, but the highly seasonal production pattern precludes this level of utilization.

Temperate species

Because of climatic influences, the high yields of tropical species are obtained during the warmer and wetter part of the year only. A major role of the temperate species under tropical conditions is to provide feed mainly in the cooler months although species such as white clover can also make some contribution throughout the year where moisture is non-limiting. On the other hand temperate grasses such as *Lolium perenne* are less persistent particularly when pastures contain an increasing proportion of warm climate grasses (Jones *et al.* 1968). If temperate species can be maintained as pure swards in the sub-tropics they can provide a valuable supplement to the predominantly summer growing species as shown by the winter-spring yields in Table 3. However their potential production falls far short of the productivity possible with tropical grasses. With mixture of temperate and tropical species under optimum conditions for growth there was a marked winter trough in dry matter production which Jones *et al.* (1968) attributed to climatic factors, but which may also be a function of the relative yielding ability of the dominant species in each season.

Forage crops

Forage crops (Table 4) are frequently grown to fill specific gaps in the feed supply provided by basic pastures. Summer crops such as the sorghums have the potential for high dry matter production similar to that available for perennial tropical grasses. Their growth is therefore coincident with peak growth of pasture but they may be useful for conservation to provide late winter, spring and early summer feed particularly in the sub-tropics. Summer legumes such as *Dolichos* and cowpeas may be useful as a supplement to more mature tropical grass pastures or in frost-free situations as autumn and early winter feed. Of the winter fodder crops, both vetch (*Vicia sativa*) and oats have been used successfully in the sub-tropics but their yields have been much lower than for tropical pastures. However, even though lower yields are produced it is available for grazing when tropical pastures are unable to provide suitable feed for dairy cows.

In summary, it may be concluded that on the basis of yield data, the quantity of dry matter that can be produced under sub-tropical and tropical conditions is not limiting for stocking rates in excess of 2½ cows/ha and may be adequate for more than 5 cows/ha. These stocking rates are much higher than those in practice even on the top producing dairy farms but are similar to stocking rates achieved experimentally (Colman and Holder 1968; Colman and Kaiser, unpublished). Even though quantity *per se* is not limiting there are problems associated with seasonal production pattern, nutritive value and utilization which restrict levels of animal production. Nutritive value and utilization problems are discussed elsewhere in this issue.

FACTORS INFLUENCING YIELD AND SEASONAL PRODUCTION PATTERN

Dairy cows during lactation require a continuity of feed adequate for both maintenance and production. Unlike sheep producing wool or meat, and beef cattle, the annual production of the dairy cow can be considerably influenced by even short periods of reduced feed availability particularly during early lactation. A good example of this effect is provided by the grazing experiment of Jeffery *et al.* (1970), in which moisture stress reduced feed supply in early lactation and resulted in reduced milk yield for the remaining production period. Thus, dairy cows, producing at a high level, place special demands on pastures, which must be taken into account when assessing the ability of a pasture to provide feed under environmental conditions typical of the region.

Solar radiation

Of the major factors of the climatic environment, solar radiation is possibly the least limiting in the sub-tropics and tropics. On the basis of data provided by Fitzpatrick and Nix (1970) radiation varies from 500 to 600 cal/cm^2/day in January to 300 to 400 cal/cm^2/day in July. During periods of summer rainfall, radiation can be reduced by 50 to 150 cal/cm^2/day but this is unlikely to severely reduce growth of tropical species.

A number of studies of pasture growth in the southern sub-tropics have included the measurement of radiation and it has been suggested as one of the reasons for lower winter growth (Jones *et al.* 1968; Bryan, Sharpe and Haydock 1971). In the former study it is doubtful whether radiation levels would have restricted the growth of temperate species; however, with *Lotononis bainesii,* Bryan, Sharpe and Haydock (1971) found that radiation accounted for 61% of the yield variation over a two year period though temperature and moisture supply are confounded with radiation and may be more important than these results indicate.

Temperature

The generalised pattern of growth by warm climate species is controlled to a large extent by temperature, if moisture is not limiting. The temperature pattern is predictable, year-to-year variation being relatively small. Over most of the sub-tropics, though to a lesser extent in the true tropics, temperatures in winter restrict the growth of tropical grasses but provide favourable conditions for temperate species. As indicated by Coaldrake (1964) the incidence of frost and its sudden onset has a large effect on production of warm climate species and can have a marked and rapid effect on feed availability.

Several studies have been made of the temperature requirements for active growth of tropical legumes. Whiteman (1968) found that for siratro, silverleaf and greenleaf desmodium and Tinaroo glycine the optimum temperature for growth was 30/25°C (day/night). Hutton (1970) found that siratro also grew well at 27/22°C, but had reduced yield at 33/28°C. Tropical grasses have a slightly greater optimum temperature than tropical legumes (being in the range of 30 to 35°C) and temperate grasses have an optimum between 20 and 25°C. Some temperate grasses continue growth down to quite low temperatures (5°C) but growth of tropical grasses is generally very restricted below 15°C (Cooper and Tainton 1968).

At least in the sub-tropics, temperatures within the ranges quoted above are restricted to approximately half the year. For example, mean monthly maximum temperatures for Brisbane are above 26.5°C (80°F) from November to March but the mean monthly minimum temperatures are always less than 25°C (77°F) (Coaldrake 1964). Further north, temperatures greater than 26.5°C mean maximum are obtained from September to April but mean minimum temperatures are less than 25°C.

It is possible that a major influence on growth is the minimum temperature which is frequently much lower than that used in controlled environment experiments and less than the average night temperature (Went 1957). The results of Coleman (1964) indicate a range in the growing season of tropical pastures of 5 to 8 months (south to north) using average night temperature as the criterion.

Rainfall

Although mean annual rainfall is high, there is a distinct seasonal pattern, with summer incidence increasing northwards. In the southern sub-tropics there is a reasonable level of winter rainfall, the period with least rainfall occurring in August to October. It is in this latter period that there is greatest risk of feed shortage from pasture and forage crops which is clearly related more to the unreliability of the rainfall than to the amount. Plant factors also are important at this time since dry weather can accelerate the maturity of temperate species and sub-tropical species may be restricted in growth due to temperature.

Unreliability of rainfall is not only important in spring but is perhaps the major factor which can influence the continuity of pasture supply for dairy cattle in the sub-tropics and tropics. The length of periods of moisture stress and the unreliability of rainfall increase with distance from the coast for the important dairying areas of north-eastern N.S.W. and Queensland. This can dictate a change in the species and methods used to provide a continuity of feed. Seasonal conditions over the period 1965/70 have highlighted the problem of rainfall reliability and the difficulty of maintaining a high level of feed supply without such costly activities as irrigation, conservation and grain feeding.

Irrigation is not applicable to dairy farms generally and is capital and labour intensive. It is therefore only in special situations that irrigation can be considered as part of the feeding system. When it is available the capital and labour involved must be compared in productivity to alternative policies of overcoming rainfall deficiency.

The overall effects of radiation, temperature and rainfall are reflected in the seasonal production pattern. The generalized effects are best shown in Fig. 1 by the light, thermal and moisture indices for Cairns and Gayndah in Queensland and Lismore, N.S.W. (Fitpatrick and Nix 1970). Also shown is the growth index for tropical grasses which reflects the combined effects of the other three indices. The highly seasonal pattern of growth particularly in the southern sub-tropics is mainly a function of the thermal index with radiation having a limited influence in spring and early summer when temperatures are increasing.

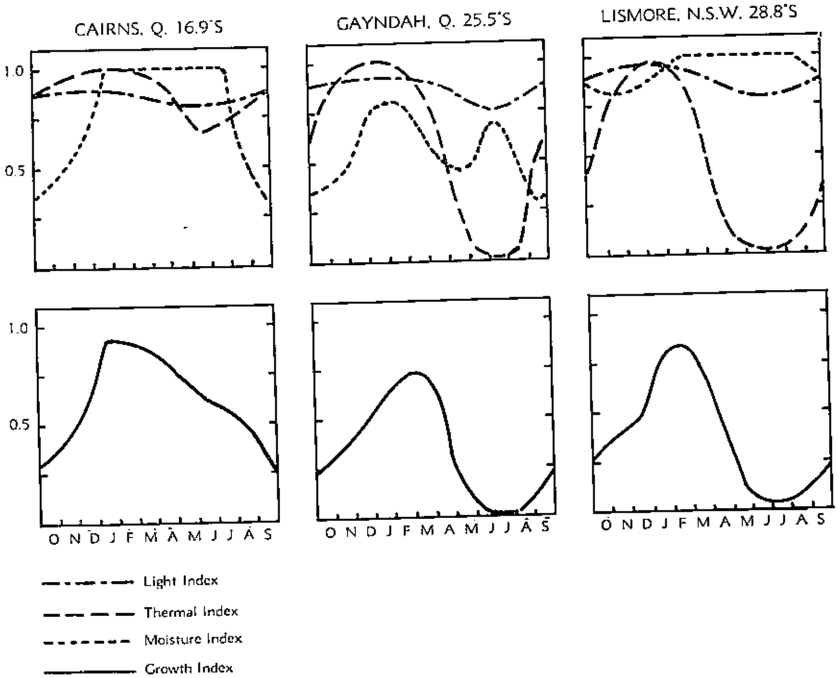

FIGURE 1

Annual trends in light, thermal, moisture and growth index values for the tropical legume group at one location in the tropics and two in the subtropics (after Fitzpatrick and Nix 1970).

These graphs fail to show the unpredictable within season climatic variations which can have a marked influence on pasture supply for dairy cows. Current technology would enable the provision of a continuous supply of feed in the sub-tropics and tropics if the available species and fertilizer technologies are used combined with such activities as conservation or the feeding of bought and farm-grown grains. It becomes largely an economic problem to determine the best combination of practices for ensuring a satisfactory return to the farmer taking into account long term trends and climatic pattern.

MODIFICATIONS TO THE GENERALIZED PATTERN OF PLANT GROWTH

Species

Overcoming the main period of feed deficiency in the sub-tropics and tropics can be approached either by attempting to increase the period of growth of the warm-climate species or by growing temperate species. Selection of warm-climate species specifically for higher winter production may be successful for grasses such as *Setaria* spp. (Hacker and Jones 1969; Roe, Jones and Rees 1970). Some of the currently available species such as kikuyu grass have a much longer growing season in the sub-tropics than cultivars of *Panicum* and *Paspalum*. Under Wollongbar conditions, growth rate of kikuyu grass has been greater than 34 kg/ha/day from September to June, some 2 to 3 months longer than a similarly treated *Paspalum dilatatum* pasture. However, kikuyu grass may only be of use in areas of high rainfall and reasonable levels of soil fertility. *Paspalum wettsteinii* may also have an extended growing season and wider soil type adaptability. Attributes such as better winter production require testing under grazing to determine their true worth for improved dairy cow feeding.

The results of species trials, presented in Table 3, indicate that there is a large range of temperate pasture plants, as yet untried extensively in practice, which may considerably improve the winter feed supply. It remains to be seen whether techniques can be evolved whereby these species can be maintained as a stable component in pastures under tropical conditions. Even with the extension of the growing season of tropical species and the use of temperate species, it is most unlikely that "out of season" production could be matched with that of the summer pastures.

Fertilizers

Nitrogen is frequently limiting growth of graminaceous species in the sub-tropics and tropics even though such factors as moisture and temperature are adequate for growth. Spring and autumn application of nitrogen to mixtures of tropical legumes and grasses and pure grass swards has resulted in large increases in productivity. In some years nitrogen can be more limiting than moisture in spring and substantial responses by kikuyu grass to early spring nitrogen top-dressing have been measured (Colman, unpublished data). Other grasses may also respond provided temperature and moisture are not limiting. Nitrogen fertilizer provides an extremely flexible technique for modifying the seasonal production pattern of tropical grasses and can be used either routinely or when dictated by the current and potential feed supply from other sources. Such fertilizer use, like all other inputs to the system, should be compared with conserved feed or concentrate feeding.

Autumn saving and conservation

Carrying feed in the paddock from periods of excess growth to times of low growth has been the basis for dairying in much of the sub-tropics but has resulted in low production both per cow and per hectare. The efficacy of such a technique may be more a function of quality than of quantity of feed. Conservation of tropical species has been generally neglected. Some tropical pasture and crop species make good quality silage (e.g. maize) but the ensiling process invariably results in decline in nutritive value. Modern methods such as vacuum silage in plastic may be useful for increasing the percentage utilization of a large summer peak of pasture and forage crop production without greatly increasing costs.

PLANT FACTORS INFLUENCING PASTURE YIELD

There are several aspects of pasture and forage crop production which are applicable to all the grazing industries. These include establishment of sown species, mineral nutrient requirements for establishment and maintenance, nodulation and nitrogen fixation and pests and diseases. These factors can considerably influence the feed supply for dairy cows and with the exception of the predetermined mineral nutrient requirements are essentially unpredictable.

The importance of establishment of sown species has been clearly indicated in the review of Campbell (1969). In the sub-tropics of N.S.W. variable establishment has been cited as a factor influencing production of newly sown tropical legumes (Swain *et al.* 1970). With species which have a limited ability to regenerate from seed such poor establishment can considerably reduce both total yield and longevity. Much research is needed to define and solve the establishment problems of perennial tropical pasture species. These studies should include seed and seedling physiology studies such as those of Murtagh (1970) and such laboratory work should be linked with the field situation whenever possible.

Survival and high production of tropical legumes are dependent on effective nodulation. Little is known of the ecology of tropical *Rhizobium* particularly in regard to their persistence following initial successful nodulation. Failure of innoculant strains of bacteria to persist could be one of the factors affecting stability of the legume under grazing and in competition from vigorous tropical grasses. Future research (Date 1970) should indicate the extent of this problem.

The importance of mineral nutrition in determining herbage production in the tropics is no less than in temperate regions. Under dairying conditions the rapid correction of nutrient deficiencies may be important for maintaining a continuity of feed. Diagnostic techniques such as the use of plant analysis can be of considerable value not only for determining deficiencies but also for indicating sufficiency of nutrients (Andrew 1965).

As in temperate areas, deficiencies of phosphorus and sulphur are important in the tropics (Andrew and Bryan 1955, 1958; Andrew and Robins 1969a, b), the use of superphosphate being vital for the maintenance of high levels of growth and nitrogen fixation. Other nutrients such as calcium, potassium, copper, zinc, molybdenum and boron are also deficient depending on soil type. Healthy legume growth depends on the correction of these deficiencies.

Excesses of manganese and aluminium on acid soils have affected growth of some legumes (glycine and lucerne) and it was concluded by Andrew and Hegarty (1969) that tropical species were as much affected as the temperates. These mineral excesses may be of importance on soils currently used for dairying and would be increasingly evident with more intensive production.

The major insect pests of tropical pastures are weevils which feed mainly on legumes. Clover root weevil (*Amnemus*) and white fringed weevil can cause severe damage to both tropical and temperate legumes though the former insect feeds much less on siratro and lotononis than on other tropical legumes. The white fringe weevil appears to have a much wider host range. Control of these pests is difficult because of the long period of egg laying and larval development. The most effective insecticide, Dieldrin, is absorbed by animals grazing treated pasture and is therefore an unacceptable control chemical (Braithwaite, Jane and Swain 1958; Braithwaite 1959).

The black beetle, larvae of which feed on grass roots, can cause damage to both pastures and crops and herbage-feeding insects such as sod web worm and army worms can rapidly remove the available green feed. All these insect pests if unchecked can reduce the pasture yield and are therefore a threat to the continuity of feed from pasture systems.

Plant diseases have so far not been a serious problem with pastures in the tropics though isolated outbreaks of virus diseases on legumes have been observed. A number of leaf spotting organisms have also been observed but damage was minimal. A disease known as "kikuyu yellows" has infested areas of kikuyu grass in the Richmond district, N.S.W. but has not caused complete destruction of pastures. The cause of the disease has not been determined (Allen, personal communication).

CONCLUSIONS

The potential is great for producing feed for dairy cows in the tropics. Using current technology it is possible to produce sufficient dry matter for feeding many more animals than are currently being carried. Thus, quantity of feed is not a problem under tropical and sub-tropical conditions if current species and technologies are used.

The most important limiting factor is the time sequence of production and the fact that a large proportion of the total yield is produced over a relatively short period. In addition there are the erratic within-season variations of feed supply which have the greatest influence on dairy cow production.

Overcoming these periods of feed shortage may be difficult without the use of technologies, such as conservation and grain feeding, which are currently not favoured because of cost and labour requirements. Further research may indicate the value of these techniques. It may be more economical to maximise production within the framework of a limited number of species and pasture improvement methods which can be easily used to exploit the environment. Production from such a system would fluctuate with seasonal conditions but this may be more economic than the use of techniques which maintain a uniform level of production year-by-year but substantially increase costs.

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