CLIMATIC AND BIOLOGICAL LIMITATIONS TO DAIRY PRODUCTION IN A TROPICAL ENVIRONMENT

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INTRODUCTION

The aim of this paper is to highlight "the basic exogenous differences between tropical and temperate dairyfarming situations (in Australia) which affect performance or require modifications in production methods". In keeping with this concept, the tropical situation includes sub-tropical areas characterised by rainfall with a relatively distinct summer incidence supporting the growth of predominantly summer-growing pasture species.

Pastures and pasture management are relatively more highly developed in Victorian dairying areas, with which comparisons are made. In Northern New South Wales and Queensland, major changes in pasture species and management are occurring and new tropical species are replacing the paspalum and Rhodes grass pastures of the pioneers. At this stage, it seems probable that the utilisation of pastures in temperate areas has reached a higher degree of efficiency than is the case with tropical species. For the decade ending 1970, average lactation yields of herd recorded cows in Victoria was 2,668 l (587 gal) compared to 2,041 l (449 gal) in Queensland.

The greatest volume of published work refers to experiments in controlled temperature rooms on the reaction of animals and effects on productivity and milk quality under hot conditions. References and bibliographies relevant to these studies appear in reviews by Bianca (1965), Johnson (1965a, b) and Mahadevan (1968).

Emphasis in this review is not placed on experiments under controlled climatic conditions but rather on work which has been aimed at the testing in a natural climate of the findings under controlled conditions. Under controlled environmental conditions it appears difficult to simulate some of the characteristics of the natural climate whilst under field conditions there are problems of differentiation between climatic and nutritional effects. Biological limitations to dairy production are concerned with interactions and reactions of plants and animals with the environment. The aspect of environment with which this review is concerned is that of climate.

The notional biological limitation concerns the ability of the dairy animal to produce efficiently in a tropical environment. World-wide and Australian experience indicates that nutritional and managerial techniques necessary to reach an efficient level of production are now well known for temperate regions. However, research workers have demonstrated distinct limitations to dairy production under continual hot and humid conditions in controlled environment chambers. Climatic effects on dairy animals are manifest in two ways—directly on the animal or indirectly through the effect on the quantity and quality of forage. Availability of soil moisture is a major determinant of forage production in a tropical climate. This aspect is considered in some detail on a comparative basis.

CLIMATE COMPARISONS

The significance of climatological factors in determining dairy production in the tropics and sub-tropics can be best illustrated by comparison with the highly productive temperate dairying area, Gippsland in Victoria.

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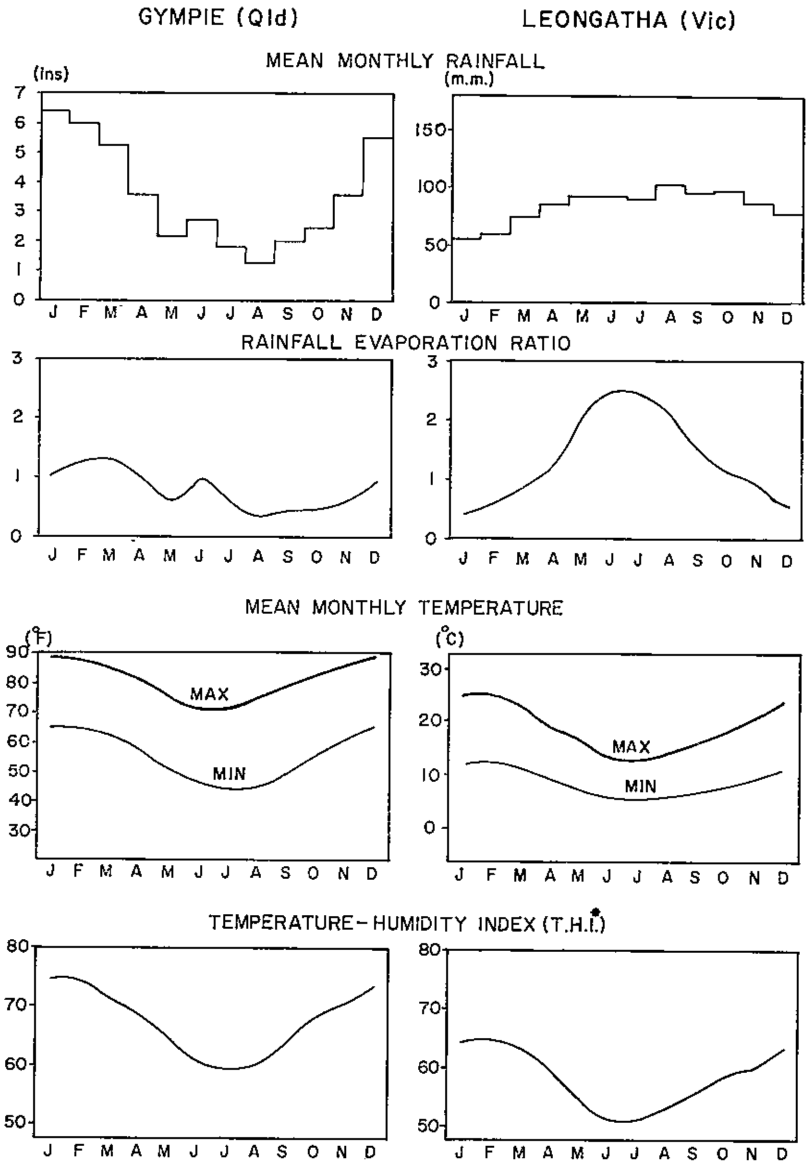

*T.H.I. = 0·55 (Mean Temp) + 0·2 (Dew Pt) + 17·5 (in °F) (Johnson, 1965)

Source: "Climatic Averages, Australia" (Bureau of Meteorology, 1956)

SEASONAL TRENDS IN CLIMATIC ELEMENTS FOR GYMPIE (Qld) AND LEONGATHA (Vic)

(FIG I)

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Seasonal trends in climatic elements for Gympie representing a sub-tropical environment and Leongatha in the Gippsland region, Victoria, (representing a temperate environment) have been plotted in Fig. 1. Annual rainfall of both centres is in the vicinity of 1000 mm (40 in.). The major difference in rainfall is in seasonality with a 68% summer component (November to April inclusive) at Gympie compared to 45% at Leongatha. Variability of rainfall is much higher in Queensland. Leeper (1964) concluded that summer rainfall in Australia was less reliable and winter rainfall more reliable than in other parts of the World. Rainfall intensity at about 10 mm (0.40 in.) per wet day is also greater than a typical Victorian figure of about 5 mm (0.20 in.) per wet day.

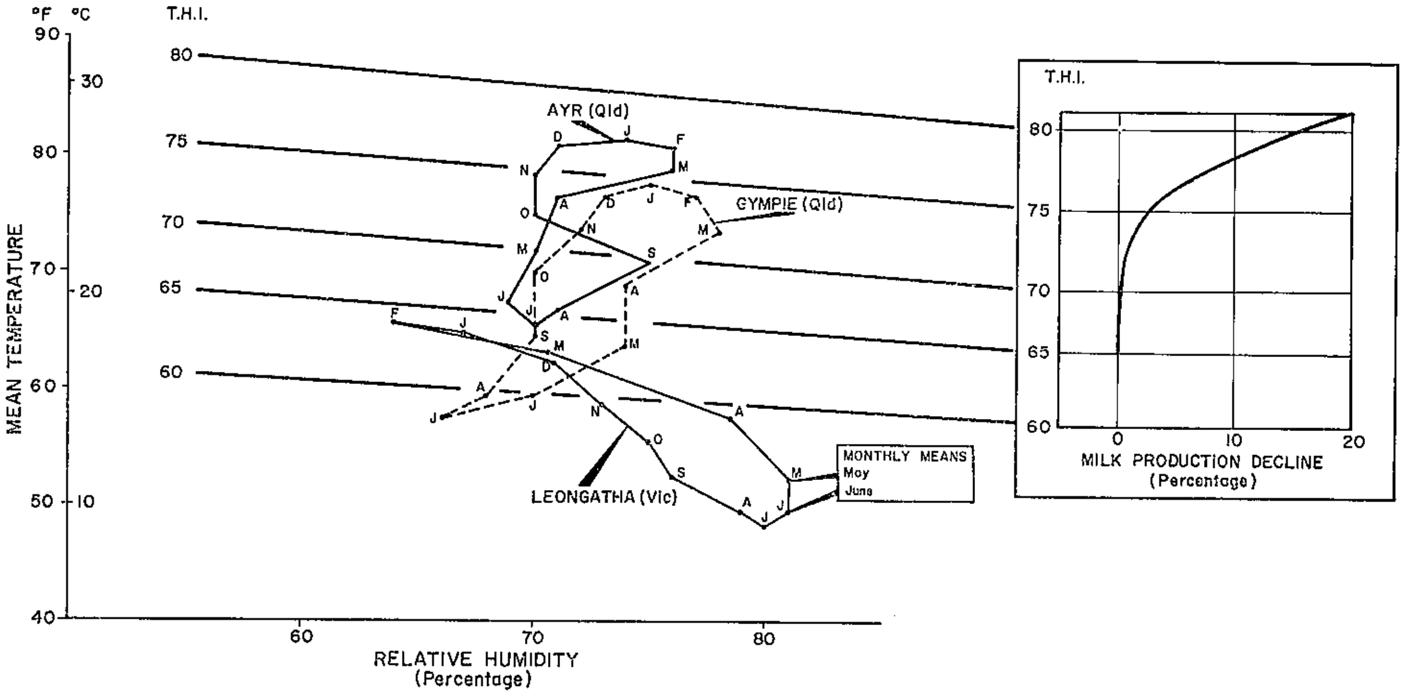
The rainfall/evaporation ratios plotted in Fig. 1 indicate the gross seasonal trends in the effectiveness of rainfall for plant growth. The values of the ratio in Victoria indicate that rainfall limits plant growth for at most a few months of the year. In Queensland, values are much lower with the exception of December to March and June. Although the winter rainfall component is low in Queensland, growth potential is enhanced by relatively lower evaporation rates.

Mean monthly temperatures for Gympie and Leongatha are also plotted in Fig. 1. The major differences are the higher values, particularly maximum temperatures, at Gympie and the greater diurnal and annual range at Gympie. Radiation levels have not been plotted but in general maximum values in the humid tropics are similar to those in temperate areas because of increased cloud cover in the tropics during summer.

Fitzpatrick and Nix (1970) have analysed the climatic factor in Australian grassland ecology using moisture, temperature and light indices. The major limiting factors are the temperature regime in Victoria and the moisture regime in Queensland. As the seasonal temperature regime in Victoria is of low variability from year to year, the timing of pasture growth "flushes" is highly predictable and an optimum management pattern can be adopted. In Queensland, where moisture is the main limiting factor, pasture growth periods producing quality pasture are less predictable and of shorter duration because of higher evaporation, and higher rainfall intensity and variability.

Direct effects of climate on livestock comfort arise from the interplay of a number of climatic elements which vary diurnally and seasonally. The most important factor, temperature, is modified by humidity, radiation and wind. Johnson (1965a) has used a temperature humidity index (T.H.I.) to relate climate and milk production. The seasonal trends in monthly means of this index are shown in Fig. 1.

In Fig. 2, climographs of mean temperature and humidity for Gympie and Leongatha are illustrated with T.H.I. isopleths superimposed. Johnson's (1965a) relation between decline in milk production and T.H.I. for high, medium and low producing cows has been standardised by using percentage declines. Mean T.H.I.'s at Gympie do not exceed 75 for which the production decline is only 2%. Heat wave periods with T.H.I.'s near 80 could occur but there are few data available to suggest the immediate and lagged effects of brief exposures to stress conditions. In general, it appears that the direct effect of heat stress over the whole lactation at Gympie is minor.



Temperature and Humidity Data Source: "Climatic Averages, Australia." (Bureau of Meteorology, 1956)

CLIMOGRAPHS SHOWING T.H.I. LEVELS FOR GYMPIE (Qld), LEONGATHA (Vic) AND AYR (Qld) AND THE RELATION FROM JOHNSON (1965) BETWEEN T.H.I. AND MILK PRODUCTION DECLINE

(FIG 2)

Climatic effects on the animal

General

When classified in relation to their temperature regulating system cattle are classified as warm-blooded animals or homeotherms. Homeotherms possess greater adaptability to environmental conditions than organisms at an earlier evolutionary stage. Variations in the rate of metabolic processes are minimised as the temperature of the body is kept relatively constant. Any variation in temperature in the intact body elicits responses which tend to restore temperature to normal.

The four major climatic characteristics having a direct effect on cattle are temperature, humidity, air movement and solar radiation. In outlining the effects of these characteristics emphasis is placed on heat exchange as being by far the most important aspect under tropical conditions.

Normal temperature of the bovine is approximately 38.3°C (101°F). Johnson (1965a) states that if body temperature rises 4.4°C (8.0°F) above normal, it is often quickly fatal. Within the ambient temperature range, 1.7°C-18.3°C (35°F-65°F) body temperatures of cattle can be maintained at normal level with very little adjustment of body processes. This temperature range is referred to as the zone of thermal neutrality or thermal comfort.

Johnson (1965a) quotes data from various sources indicating the upper limit of the comfort zone for different breeds and different functions. These are summarised in Table 1.

TABLE 1

Upper Limit of 'Comfort Zone' Air Temperatures

Breed	Activity							
	Lactating Cows		T.D.N. Intake		Milk Production		Air Temperature at which rectal Temperature rose by same amount	
	°C	°F	°C	°F	°C	°F	°C	°F
Holstein	21	(70)	21	(70)	27	(80)	27	(80)
Jersey	24	(75)	24	(75)	29	(85)	28	(82)
Brown Swiss	27	(80)	27	(80)	29	(85)	28	(82)
Santa Gertrudis							38	(100)
Brahman	35	(95)	35	(95)	35	(95)	43	(110)

At temperatures below 21°C (70°F) changes in humidity have very little influence on animal comfort or adaptation. At higher temperatures increasing humidity causes increasing difficulty in heat regulation by inhibiting the evaporation of water from the body surface. The interaction between temperature and humidity has led to the development of the temperature—humidity index (T.H.I.) for dairy cattle. According to Johnson (1965a) the following formula for the T.H.I. equation was proposed by the U.S. Weather Bureau (Anon. 1959): T.H.I.=0.55 x (D.B.)+0.2 (D.P.)+17.5; D.B. and D.P. refer to dry-bulb and dew-point temperatures respectively in degrees F. Air movement facilitates dissipation of heat through both convection and evaporation at temperatures above 21°C (70°F). At temperatures below that of the body surface increasing air movement increases loss of heat by convection. Air movement has little effect on regulation of temperature in the upper portion of the 'comfort zone' but at lower temperatures it leads to earlier need for adjustment to prevent a fall in body temperature.

Solar radiation adds to the heat load. In direct sunlight an animal absorbs heat from the sun's rays, and can also absorb some from the ground and other surrounding objects. It follows that under conditions of similar temperature an animal has a greater heat load on a clear sunny day compared to a cloudy day and also when exposed to the sun in comparison to the shade.

The elements of temperature, humidity, air movement and solar radiation determine the climate. The extent of stress on animals depends on the combination of these factors, the duration for which a given combination exists and the adaptability of the individual animal. For short periods, it appears that cattle can tolerate extreme conditions which cause disturbance of the equilibrium between heat production and heat loss, provided they are followed by periods during which recovery can take place.

Effects on productivity

From the controlled environment chambers, questions arise concerning the degree of applicability to the field situation. Work reported from Missouri (Le Roy Hahn *et al.* 1969) confirmed the predicted decline in productivity under stress conditions as indicated by high T.H.I. values. A high degree of correlation was demonstrated between actual and predicted milk yield declines postulated by Johnson (1965a) as a result of experiments under controlled environment conditions.

In the experiments reported by Hancock and Payne (1955) and Payne and Hancock (1957) one member of each of eight pairs of identical twins was transported to the tropical climate of Fiji while the other members remained in New Zealand. The transfer to Fiji occurred when the animals were 7½ months of age. Feeding and management in the two countries were uniform, the animals being confined outdoors in a bare yard with access to shade and free access to water. All animals were fed on lucerne hay, barley-meal and extracted copra meal with added minerals and vitamins. Thus, the experiment was designed to assess the direct effects of climate. Considering firstly growth rate, the period from March 6, 1950, when the twins were first separated, to June 25, 1951, was divided into five phases, each of approximately three months' duration. Differences in growth rate were small being somewhat less than 10% pre-calving and narrowing to 3% at the end of first lactation. During the January-April period all the Fiji members had a lower feed intake and markedly lower efficiency of conversion of intake to liveweight gain. However, over the 60-week period two of the Fiji members had higher forage intake than their New Zealand counterparts. Large between-set differences occurred in growth rate and in general four twin sets were less adversely affected by the Fiji climate than were the remaining sets. Although the onset of high summer temperatures checked the growth of each animal in Fiji, this check varied between sets, not only in its degree of severity but also in its persistence. This experiment provides no information on comparative birth weights and growth rates of calves. Data from Kairi Research Station in Far North Queensland quoted by Strachan and Mawson (1962) indicate that the growth rates of Jersey heifer calves to 150 days compares favourably with U.S.A. standards for this type of animal. The Kairi Research Station is at a latitude of 17°S but the elevation of 715 m (2344 ft) provides a moderating climatic influence. The Fiji identical twin study was continued to assess the effect of a tropical climate on production. Results were obtained for the first lactation only. Due to sickness of the experimental animals, only two of the original eight pairs of animals provided production data uncomplicated by this factor. The authors stated that these factors coupled with a large discrepancy in calving dates of another set, reduced the value of any complex analysis and the results were presented in a relatively simple form. Milk production was considerably higher in

New Zealand (44% more)but failed to reach statistical significance (P=0.05). Of importance is the fact that the Fiji members of two sets produced slightly more milk than their New Zealand mates, indicating a considerable variability in animal reaction to tropical conditions. A significant difference (P=0.05) was obtained in 4% fat-corrected milk. However, some discrepancy in milking methods may have had an influence in this respect. In general, the lactation curve of the Fiji members was different—failing to rise to an expected peak during the second month and then falling off rather rapidly. With reference to feed intake during lactation, the Fiji members ate their total ration of grain but ate less of the hay to which they had free access compared to those in New Zealand. The starch-equivalent intakes per kg of milk were similar for the twins in both climatic environments, so that average efficiency of production was much the same. Water consumption by the Fiji members was significantly higher by an average of 4.2 l per kg (3.35 pints per lb) of milk produced. Normal rectal temperature and respiration rates were maintained in the New Zealand members while levels of the Fiji members were abnormal. However, there was no significant correlation between milk production per day and rectal temperature or respiration rate.

This experiment suggests some important aspects:

1. The necessity to provide adequate drinking water to temperate type animals in a tropical environment as increased water consumption appears to be a means of off-setting hot conditions.
2. There is apparently a wide range of adaptability to hot conditions among cattle of a temperate breed, and those with a well developed adaptability are capable of a satisfactory level of production under tropical conditions when husbandry is adequate.
3. Caution is necessary in attempting to measure heat tolerance of animals by means of changes in rectal temperatures or respiration rate.
4. Monthly T.H.I. values in Fiji have a maximum value of 78. From Fig. 2 a production decline of less than 10% is indicated and a decline of this order is not incompatible with the results.

At Biloela Research Station McIntyre (1967) conducted an experiment designed to determine the effects of the time of calving on production in a tropical climate with control over nutrition. One group calved in May, approaching the coolest parts of the year and the second in November, approaching the hottest part of the year. There were no apparent differences in feed intake between the two groups. Water intakes rose slightly during hot weather. The May group produced more milk during the first two months of the experiment but differences for the remaining five months and for the whole experimental period were not significant. The higher production of the May group in the first two months may also have been influenced by the heavier average weight (51 kg) of this group at parturition. No meaningful correlation was found between dry bulb temperature, rectal temperature and milk yield. Of the 44 cows only six showed significant relationships and three of these were negative. After contrasting his results with those from experiments in controlled climate rooms, McIntyre (1967) concluded that 'the high ambient temperature and humidity combinations in themselves are not harmful to the animals if they are allowed a cooler recovery period at night, such as in natural conditions'. Maximum mean monthly T.H.I. values at Biloela do not exceed 75 and from Fig. 2, only a minor decline in milk production is indicated.

Sims and Porter (1966) reported evidence of reduction in feed intake and depression of milk yield associated with high temperatures. At a mean temperature of 24°C (75°F) intake of forage dry matter was only 90% of that when ambient temperature was under 24°C. This reduction occurred in the roughage portion of the ration. When mean daily temperatures reached 26.7°C (80°F) and above, (estimated T.H.I. of 77) forage intake fell sharply to 71% of that recorded when temperatures were below 24°C. Milk yield per unit weight of dry matter intake remained relatively constant. A significant negative correlation between high mean temperature and milk yield on the following day was obtained, suggesting that the effects of high temperatures on milk yield operated through reduced feed intake. A similar effect on milk yield was noted in the regular herd where forage intakes were not recorded. However, for the 84 day period of the trial, daily milk yields were consistently high (in the region of 27 l (6 gal) per cow daily) with the exception of the temporary sharp declines associated with periods of high environmental temperatures.

Tucker (1968) in a study of district milk quality on the Atherton Tableland (maximum mean monthly T.H.I. of 72) showed a depression in solids-not-fat of milk associated with periods of above-average temperature.

Sibbick and co-workers (personal communication) recorded rectal temperatures of lactating cows over an 11 day period in midsummer at Ayr. The data indicated a 1.7°C (3°F) increase in rectal temperature from 39°C (102°F) as T.H.I. increased from 75 to 83. Data of Johnson (1965a) show a parallel relationship between air temperature and rectal temperature and air temperature and milk production. Thus, an effect on milk production as a result of heat stress is indicated at Ayr.

Indirect climatic effects

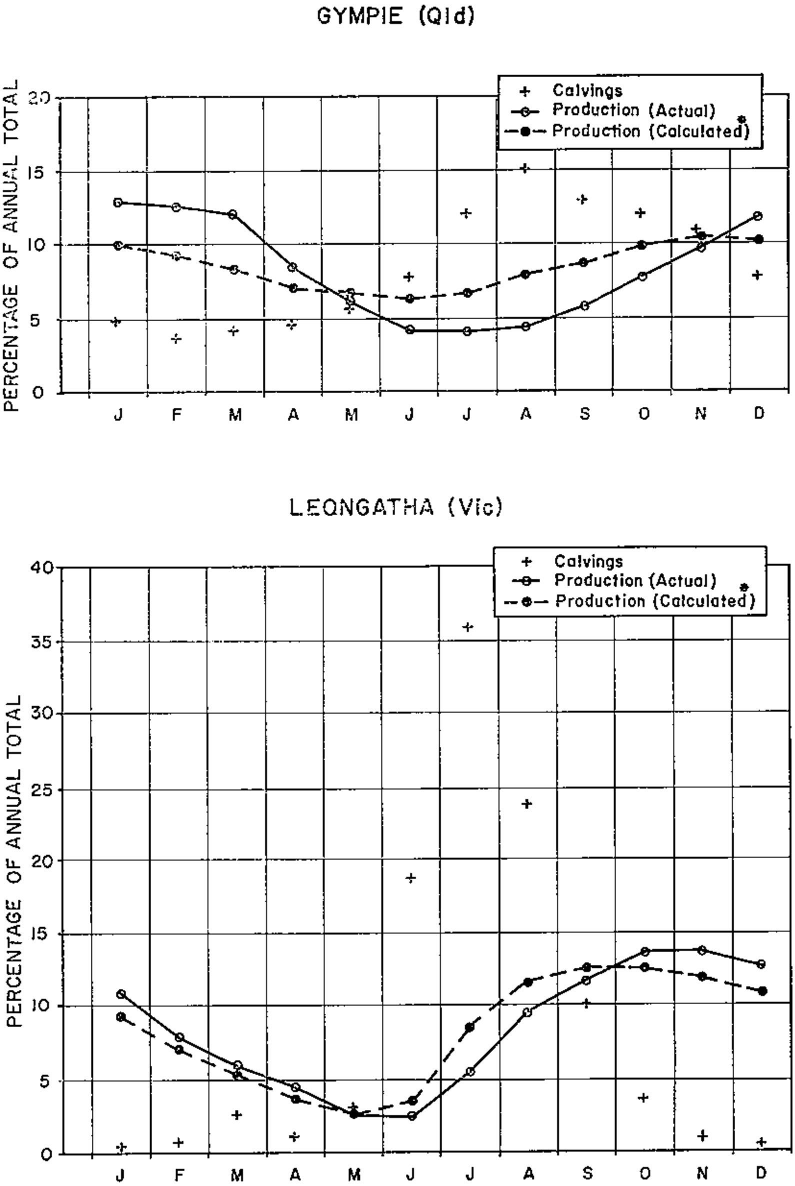
Rainfall and forage production

Objective studies on the relationship between physical environment and biological productivity are limited. Although the dairy industry is a more complex biological system than for example a grain crop, because of the delayed effects on lactation curves, etc., an understanding of the system is a prerequisite to any modifications or optimization. For example, to determine a feed-year programme, pasture supply and animal demand of the system throughout the year are required. Simulation methods and systems analysis as advocated by Nix (1968) seem to offer the most promise for a more quantitative assessment of the system. Ross (1969) discussed the value of simulation techniques as an aid to evaluating management strategies in an environment where soil moisture and temperature show wide temporal variation.

No published data are available for the tropical and sub-tropical dairying areas on functional relationships between dryland pasture or milk production and climatic factors such as soil moisture or rainfall. Waring (1968) in a study of rainfall and factory milk production at Bellbrook on the Lower North Coast of New South Wales found that over 90% of the variance in animal milk yields could be attributed to the variation of rainfall in April (three or four months before calving) and in September, October. These were the months of lowest median rainfall and greatest rainfall variability.

Swain, Bird and Dane (1970) discussing the feed-year programme on the Far North Coast of N.S.W. stated that time of calving represents a continual gamble as in only two years out of five is spring rainfall sufficient to give early growth of summer grasses and a long production season.

As nutritional requirements vary with stage of lactation, time of calving can be adjusted within constraints determined by the seasonality of milk demand. If temperatures are not limiting, irrigation can be used to modify the pasture production pattern and alter the optimum calving pattern. In Fig. 3 monthly calving and production patterns on a percentage of annual total basis are shown for Gympie and Leongatha. Calvings are much more seasonal at Leongatha with 85%



*Calculated production determined by applying a standard lactation curve to cows calving in each month:

SEASONAL TRENDS IN CALVINGS AND MILK PRODUCTION FOR GYMPIE (Qld) AND LEONGATHA (Vic)

(FIG 3)

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of the annual total over the period June to September. Spring is also the period of maximum calving in Queensland, although not to the same extent as in Victoria. The Victorian production pattern takes full advantage of the reliable pasture flush in spring when temperatures increase and moisture is not limiting. In Queensland, spring from the aspect of pasture growth initiation, is more myth than reality. Calculated productions based on the calving pattern and assuming a standard lactation curve independent of time of calving are also shown in Fig. 3. The calculated pattern shows the seasonality of production assuming that no nutritional restrictions apply. This pattern is dependent only on the stage of lactation for time of calving groups in each month. For Leongatha, the calculated and actual curves show little divergence excluding the late winter period. For Gympie, calculated production shows less seasonal variation than actual production. If the lactation curve were independent of nutritional stress, higher levels would be recorded over the June to October period and relatively lower levels from December to April. June to October is the period of nutritional stress determined by the seasonal rainfall and temperature regimes and December to April corresponds to the period when high quality pasture is available.

To quantify the approximate effects of nutritional stress as indicated by rainfall seasonality, a regression analysis was done on the effects of quarterly rainfall and factory-milk production in the previous quarter on quarterly milk production in the present quarter for nine factories in south-east Queensland (Table 2).

TABLE 2

Percentage Effect on Quarterly Milk Production per Rainfall Standard Deviation

Centre	Annual Rainfall		Quarter			
	mm	in.	October November December	January February March	April May June	July August September
Maleny	1979	77.92	8.0*			7.8*
Pomona	1487	58.56	7.8	6.5*	10.1*	
Gympie	1146	45.13	9.4			9.4
Biggenden	870	34.25	9.7*	9.4*		
Wondai	800	31.46	6.3*	6.5	11.2*	
Gayndah	786	30.94	15.7*	8.2**	14.5	
Goombungee	688	27.07	6.8*			
Miles	622	26.05	13.2*	8.9		
Crow's Nest	835	32.89	7.8*	6.8	11.3	

Significance Levels		
	**	1 per cent
	*	5 per cent
	Not stated,	10 per cent

Rainfall effects were much greater overall in the October to December quarter, which is a period of variable storm rainfall occurring just after the months of peak calvings. October to December is generally the most difficult period of the year because pasture availability is at a minimum after winter. In the wet season months January to March, rainfall effects were generally greatest in the more marginal lower rainfall dairying areas. Fewer centres responded to rainfall in the April to June and July to September quarters. Because of the calving pattern, cows are at a later stage of lactation or dry over this period and total production is at a low level. In addition, a lower response to improved nutrition could be expected in late lactation.

The above preliminary analysis suggests that more refined estimates of the relationship between environment and production are possible. The climatic factors influencing monthly production could be determined using water balance techniques for soil moisture as demonstrated by McAlpine (1970) and pasture growth models as developed by Fitzpatrick and Nix (1970).

Minson and McLeod (1970) concluded that climatic factors are associated with the generally lower digestibility of tropical grasses. They found that digestibility of tropical and temperate grasses were equal when grown under the same conditions and that digestibility was highly correlated with temperature.

Downes (1970) has shown that tropical grasses have twice the water use efficiency of temperate grasses. A major advantage of the tropics and sub-tropics as illustrated by Stewart (1970) is the potential to produce very high dry matter yields because of higher levels of radiation and temperature if moisture is not limiting. Thus, irrigation can substantially increase productivity. However, because of the variability of rainfall and thus run-off and high evaporation rates, the safe annual yield of an irrigation storage may be much lower in a sub-tropical environment compared to temperate regions.

Associated factors

In grazing behaviour studies of beef cattle on tropical pastures near Innisfail and at Ayr in Far North Coastal Queensland, Larkin (1954) found that animals were able to modify grazing behaviour according to circumstances of climate and feed intake. In studies on dairy cattle at Wollongbar, Holder (1960) has arrived at similar conclusions.

Although disease conditions have been excluded from consideration at this conference, two which are confined to a tropical and sub-tropical environment should be noted. These are ephemeral fever and the parasitism and associated disease problems of the cattle tick (*Boophilus microplus*).

CONCLUSIONS

Studies in controlled environment chambers indicate that heat stress occurs in bovines, the degree depending on species, breed and activity. These effects are manifest as increases in respiration rate, temperature, and water intake, together with decreases in feed intake and production.

From this review of field studies, a T.H.I. of approximately 75 is the level beyond which marked productivity declines begin to appear. In a non-arid climate this corresponds roughly to a daily mean temperature in the vicinity of 25.6°C (78°F). The decline in productivity appears to be a consequence of a reduced feed intake. The apparently critical level of a T.H.I. of 75 would only be exceeded for brief periods in midsummer in sub-tropical areas of N.S.W. and Queensland and for up to five months of the year in tropical coastal Queensland. Tropical coastal areas for which T.H.I. exceeds 75 for several months have annual mean temperatures exceeding 21°C (70°F) which according to Wright (1954) is a rough critical borderline as regards heat tolerance.

Adaptability of some animals is such that exposure to stress conditions for discontinuous periods may not result in a serious depression of production over a lactation. For example, high production levels per cow and per acre have been recorded in tropical Queensland with irrigation. A pure-bred herd of 37 cows at Bowen, climatically similar to Ayr, has averaged 213 kg (468 lb) of butterfat per cow.

It is thus concluded that managerial and husbandry practices can be devised and animals selected to overcome the climatic constraints of sub-tropical and tropical dairying areas in New South Wales and Queensland.

The major environmental problem is the adequate supply of a ration of suitable quality and composition throughout the year. The seasonality of climate, particularly rainfall, temperature, and rainfall variability present a number of complex probelms in developing a feed-year system but the tropical climate also presents a wider range of options compared to temperate regions. Forage production possibilities available to provide a more even level of nutrition throughout the year, include either rain-grown or irrigated tropical and temperate pastures, fodder crops and fodder conservation. A more systematic approach to the supply of and demand for nutrients over the feed-year as influenced by climate and management would aid in resolving the basic exogenous limitations to increased productivity.

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DISCUSSION

Availability and application of technology in tropical areas

In the main, tropical dairying areas suffer from a lack of highly productive permanent pastures. When a basic pasture type is not defined, pasture systems tend to become complex and hence less attractive to farmers. Factors resulting in a low level of acceptance of known practices include the complexity of pasture systems, the variability in response to improvement, and sociological, financial and political considerations.

Quantifying the effect of climate

Basic climatic disadvantages of tropical areas are higher potential losses of nitrogen and greater variability in moisture supply. A basic advantage is the longer season of suitable temperature for growth. It is highly desirable to be able to explain yield fluctuations in terms of measurable climatic and other environmental effects. Such information will considerably aid the formation of varying feed-year strategies, especially in making adjustments for different ecological zones.

The overall feed-year strategy which is chosen should accommodate likely climatic fluctuations by defining variations in feeding procedures during different weather patterns, e.g. wet versus dry springs. Such modifications are too numerous to be defined through ad hoc *experimentation and must be derived from an understanding of the basic processes.*

More research is required into ways of quantifying the effect of weather on pasture growth. As moisture stress is frequently the major limiting factor, particular emphasis should be based on this aspect. Such research should attempt to define which climatic parameters should be measured and how such data should be transformed into a form which is correlated with animal or pasture production.

Two schools of thought exist as to where the immediate emphasis should be placed:—

(i) monitor selected environmental variables during appropriate grazing experiments in order that the climatic environment, pasture and animal parameters will be available for the study of their inter-relationships. Basic parameters to be measured are rainfall, evaporation, temperature and soil moisture; the latter can be estimated by soil moisture budgeting techniques.

(ii) encourage environmental physiology studies as a basis for defining the functional relationships. Such studies should precede any attempt at studying the environment—pasture production—animal production complex.

The temperature-humidity index can be used to broadly define those regions where Bos taurus *cattle may suffer heat stress. However, the index is highly empirical and the relationship between heat load effects and the temperature-humidity index must be established under field conditions before it can be used as a descriptive tool.*

Cutting experiments

Cutting experiments provide valuable background information for the current design and interpretation of grazing experiments. Insufficient cutting experiments have been conducted in tropical areas to provide a thorough understanding of factors which affect pasture growth. Such background information is essential for the correct design and interpretation of grazing experiments.