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The Influence of Weather on the Quality of Tropical Legume Pasture During the Dry Season in Northern Australia. IV Geographic Variation in Risk of Spoilage of Standing Hay

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Abstract

This paper assesses the geographic variation in nothern Australia of the risk of deterioration to the point of 'spoilage', including both the beneficial and the deleterious effects of rain. The procedure is a modified water balance in which leaf shedding is driven by decline in soil water storage, and moulding is governed by the rate of evaporation following a rainfall of 2 mm or more.

For 28 stations, from the West Kimberley to Central Queensland, an average of 40 dry seasons have been analysed for the periods when the legume would have been green, dry but unspoilt, and spoilt. A 'dry leaf' nutritional strategy is feasible where the dry seasons are reliably rainless. Even in regions with a high risk of rain, if green leaf is maintained for a considerable time in the dry season there is also a low risk of spoilage, and the use of non-deciduous legume species in these regions and elsewhere is discussed.

Introduction

Previous papers in this series have elucidated the way in which weather controls the haying-off of Caribbean stylo (*Stylosanthes hamata* cv. Verano) pastures, subsequent quality losses of dry leaf, and the consequences of moulding and leaching on acceptability and nutritive value (McCown *et al.* 1981*b*; McCown and Wall 1981; 1989). Models were presented which enable the simulation of leaf shed and subsequent moulding from weather data inputs. In this paper we use these models to examine geographic and year-to-year variation in the potential contribution of dry legume leaf to cattle nutrition in tropical Australia.

The early history of stylo pastures in tropical and subtropical Australia records that the production of cattle on pastures containing the annual Townsville stylo greatly exceeded that on native grass pastures in contrasting dry season climates. In the continental climate of Katherine, N.T., cattle licked up dry leaf which remained highly nutritious during the rainless dry seasons (Norman 1970). At coastal Rodd's Bay, where dry season rainfall events are relatively common and dry leaf deteriorates rapidly, benefits of Townsville stylo were also reported (Shaw 1961). Benefits here were due to rain prolonging green leaf duration, enabling this annual legume to provide green feed throughout some dry seasons (Shaw and Norman 1970).

The discovery of large benefits from a tropical pasture legume at Katherine and Rodd's Bay, situated at locations at opposite geographic and climatic extremes of the northern pastoral region, raised expectations that similar potentials existed at intermediate locations. This paper provides an explanation for the fact that these expectations have not been fulfilled. It does so by analysing the complexity of the relationship between animal production, pasture botanical composition, and dry season weather. This is made possible by use of models of pasture phenomena of crucial importance to the animal's nutrition and

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simulating variation in nutritional attributes using actual weather data for numerous years at a network of stations. Most importantly, this approach enables discrimination between beneficial and deleterious effects of rainfall. Rain on a terminally water-stressed pasture prolongs green leaf availability, but it also may cause deterioration of nutritional value in leaf which has fallen. The feasibility of a 'dry leaf' nutritional strategy depends on the risk of wetting of dry leaf. This is determined by the timing of leaf shed as well as the timing and duration of wet conditions.

Ultimately, this paper seeks a climatic basis for designing optimum pasture improvement strategies by quantifying the variation in conditions for both retention of green leaf and preservation of the quality of dry leaf.

Methods

General Approach

The main weight gain and loss periods of cattle grazing native pastures in northern Australia can be simulated from climate data. McCown (1981*a*) demonstrated this using a pasture Growth Index computed from soil water availability, (simulated from weekly rainfall and pan evaporation), and mean weekly temperature. He established Growth Index criteria for a Green Season which correlated well with the period of cattle weight gain. The first week of the Green Season, (GOWK), is when native pasture Growth Index reaches 0·1 and maintains this in 2 of the next 3 weeks and 5 of the next 7, provided this is after week 35. The last week (STOPWK) is the first of 2 consecutive weeks in which native pasture Growth Index is less than 0·1, after reaching its maximum value for the last time prior to week 13. The Dry Season is the complement of the Green Season, and predicts the period of weight loss. The terms Green Season and Dry Season (capitalized) are hereinafter used as defined above.

Legume pasture can alleviate the Dry Season 'protein drought' with green leaf, and with dry, shed leaf provided it has not been spoilt by rain. The transition from entirely green to entirely dry is of course progressive, but we have arbitrarily defined the end of the legume green phase to be when 75% of leaf has fallen. Not only is this a large proportion, but in Part I we found that the last 30% of leaf was shed at a much slower rate. The dry leaf phase extends from that time until moulding reaches a defined level.

We have simulated each Dry Season and these phases of an associated Caribbean stylo pasture (or component), for a network of 28 northern stations, over an average of 40 years (Table 1).

Caribbean Stylo Leaf Shedding

Although leaves are senescing, falling, and decomposing during much of the growing season, we refer here to the leaf shedding which occurs at the end of the season due to water stress. When the season terminates abruptly, falling leaves accumulate on the ground, and if the environment remains dry, are well preserved. Little new leaf is produced during this period, so total leaf remains constant, and we need to predict what proportion has fallen at any time and is subject to spoilage by rain.

The water balance model requires weekly rainfall, evaporation, and mean temperature. In Part I, evaporation was Class A pan, converted for the water balance calculations to equivalent Australian tank by multiplying by 0·85 (McCown *et al.* 1981*b*). For this paper we used the long-term weather data from McCown (1981*b*), in which evaporation is either Australian tank or 0·85 of Class A pan. For each station the number of years in the rainfall record, and source of evaporation and temperature data (actual values or values derived from maps of monthly means), are given in Table 1. As explained in Part I, we used a crop coefficient of 1 for Caribbean stylo, 0·75 for native pasture.

From Part I, Fig. 4, substituting WI (Water Index) for G.I. gives

$$\text{Leaf shed (\%)} = 73{\cdot}1 - 77{\cdot}7*\text{WI} \qquad \text{WI} > 0{\cdot}1 \qquad (1)$$

Solving for zero leaf shed yields WI = 0·94, hence the range of WI in (1) must be restricted to 0·94 > WI > 0·1, and we can add

$$\text{Leaf shed (\%)} = 0 \qquad 1{\cdot}0 > \text{WI} > 0{\cdot}94. \qquad (2)$$

After WI drops to 0·1 (65% leaf shed), equation (1) is no longer useful, and we suggested for this period a linear relationship between time and percentage leaf shed. A suitable equation is:

$$\text{Leaf shed (\%)} = 65 + 4{\cdot}17*T \qquad 9 > T > 0 \qquad (3)$$

$$\text{Leaf shed (\%)} = 100 \qquad T > 9, \qquad (4)$$

where T is the number of weeks from WI = 0·1.

The regression was constrained to pass through the point (0, 65) in order to preserve continuity of leaf shed with (1).

Table 1. Index to Stations

Station coordinates, elevation, length of rainfall record, mean time legume is green, dry but sound, and spoilt, and sources of evaporation and temperature data where actual data were not available

Code	Station	S. Lat. °	S. Lat. ′	E. Long. °	E. Long. ′	Elev. (m)	Rain record (years)	Green (wks)	Dry Sound (wks)	Dry Spoilt (wks)	Evap. data	Temp. data
1	Derby	17	19	123	38	16	27	0·0	18·4	10·4	M	
2	Gibb River	16	26	126	26	488	35	0·2	17·7	7·6	M	A
3	Kalumburu	14	18	126	39	23	35	0·0	17·0	3·2	M	B
4	Newry	16	03	129	16	100	31	0·2	20·5	5·1	M	C
5	Darwin	12	27	130	50	28	66	0·0	16·8	0·9	M	
6	Adelaide R	12	55	131	14	52	25	0·2	18·1	1·6	M	D
7	Katherine	14	28	132	16	107	58	0·2	20·4	2·2	M	
8	Normanton	17	40	141	04	10	61	0·0	19·5	6·1	P	
9	Mitchell R	15	29	141	44		51	0·0	18·6	2·7	M	
10	Weipa	12	41	141	53	23	24	0·1	14·9	2·1	P	
11	Coen	13	57	143	12	193	64	0·3	12·6	5·9	E	
12	Laura	15	34	144	27		59	0·0	11·2	4·9	M	F
13	Palmerville	16	00	144	04	210	54	0·2	9·1	4·3	P	
14	Walsh R	16	40	144	00		39	0·2	15·0	5·6	M	G
15	Georgetown	18	17	143	33	300	36	0·3	13·9	9·0	P	
16	Mt Surprise	18	09	144	19	453	32	1·3	11·8	7·7	P	
17	Chillagoe	17	09	144	31	351	29	0·1	10·8	10·2	M	M
18	Mareeba	17	00	145	26	335	41	2·8	7·3	5·0		
19	Mt Garnet	17	41	145	07	650	33	5·1	6·6	5·8	M	M
20	Meadowbank	18	15	144	59		14	3·9	5·3	8·5	M	H
21	Cashmere	18	08	145	20		25	6·2	4·9	4·2	M	M
22	Cargoon	20	01	144	54	708	30	0·8	11·0	11·7	M	I
23	Maryvale	19	33	145	16		29	0·9	8·4	10·8	J	K
24	Pentland	20	32	145	24	327	23	1·3	8·2	11·9	P	I
25	Woodstock	19	36	146	50	62	69	1·0	7·1	13·5	M	
26	Mirtna	21	17	146	13		45	1·3	8·1	14·6	M	L
27	Collinsville	20	34	147	51	187	33	3·7	5·7	6·8	P	
28	Rodds Bay	24	04	151	23	46	35	9·4	4·1	2·9		
	Millaroo	20	04	147	17	Used only for					P	
	Townsville	19	19	146	47	model development					N	

[A]Interpolated between Turkey Creek and Mitchell Plateau.
[B]Data from Pago Mission.
~~[C]Data from Kimberley Research Station, Kununurra.~~
[D]Data from Milton Springs.
[E]0·8 of Mt Croll Class A pan.
[F]Data from Fairview.
[G]Interpolated between Palmerville and Mt Surprise.
[H]Data from Cashmere winter and Mareeba summer.
[I]Interpolated between Hughenden and Charters Towers.
[J]Data from Clarke River.
[K]Data from Charters Towers.
[L]Interpolated between Charters Towers and Clermont.
[M]Data from monthly maps.
[N]0·8 of Davies Laboratory Class A pan.
[P]0·85 of Class A pan.

Commencement of Leaf Shedding

WI may fall below 0·94 at any time during the wet season, but we do not permit leaf shedding in the model until WI has reached its maximum value for the last time up to week 13.

Mould Development

In Part II (McCown and Wall 1981), we demonstrated that only rain can supply sufficient moisture to promote significant moulding, that at least 2 mm in one day is required, and that it is the time for which the litter is wet following rain which determines the amount of moulding.

We used discoloration as a measure of moulding, by converting the Value parameter of the 10YR Munsell Soil Colour Chart to a Discoloration Index (D.I.) ranging over 0–6 (Table 2; McCown and Wall 1981).

In Table 3 of Part II, we included pan evaporation as a factor governing duration of wetness, and we now propose a form for this relationship, based on the following assumptions.

1. Rainfall less than 2 mm is insufficient to cause moulding.
2. Rainfall in excess of 2 mm has the same effect as 2 mm, as any excess drains off.
3. Evaporation from litter is proportional to pan evaporation.

Whence

$$\text{WETIME} = \text{A}/\text{DAYEVAP},$$

where WETIME is time for 2 mm to be evaporated;
A is a constant;
DAYEVAP is pan evaporation for that day.

We chose not to regress WETIME on 1/DAYEVAP, since our geographical evaporation data are mean weekly Australian tank or equivalent, and deriving DAYEVAP from this would be a tortuous process. Instead, we sought the direct relationship between increase in D.I. and 1/Eweek, where Eweek is mean weekly Australian tank evaporation (mm).

We used the cumulative data in Tables 1 and 2 of Part II, excluding Townsville 1975 and Millaroo 1976, since they contained rainfall data of doubtful reliability. For each day of 1·9 mm or more of rain, we calculated and accumulated 1/Eweek. Excluding all D.I. values of 6, since this is the limiting value, we obtained the regression equation

$$\text{D.I.} = 79{\cdot}4/\text{Eweek}, \qquad (5)$$

where D.I. is discoloration index.

We then examined the fitted values for the excluded D.I. = 6 points, since if a fitted value be less than 6 that point should be included. One point only was thereby reinstated, and the regression was repeated. The result was little different.

$$\text{D.I.} = 79{\cdot}7/\text{Eweek} \qquad 13{\cdot}28 < \text{Eweek} \qquad (6)$$

$$\text{D.I.} = 6 \qquad 0 < \text{Eweek} < 13{\cdot}28, \qquad (7)$$

accounting for 83% of the variance.

The observed values and fitted equation are shown in Fig. 1.

Simulation Procedure

Although deterioration is progressive, we consider the legume to be spoilt when D.I. reaches 5 (dark brown or dark greyish brown). At this stage, leaf has become unacceptable to cattle (Part I) and dry matter digestibility has fallen to 50% (Part III).

Our simulation of moulding is essentially a process of cumulative discoloration. To simplify the computations when leaf is falling, we do not maintain separate pools for leaf material on the ground and in the canopy, but accumulate discoloration for the whole in proportion to that part which is on the ground. For each day having 2 mm rainfall or more, we use eqns. 6 and 7 to calculate the increment in D.I., then multiply by the proportion of leaf which has fallen before adding to accumulated D.I. The D.I. of the fallen leaf is limited to 6.

For example, let D.I. at week 10 = 1·4
Leaf fallen at week 11 = 55%
Rain events (≥ 2 mm) in week 11 = 2
Mean weekly evaporation in week 11 = 70 mm;

then

D.I. increment on fallen leaf per rainfall event = 79·7/70 = 1·14
D.I. increment on fallen leaf = 1·14*2 = 2·28
D.I. increment on green leaf = 0 (green leaf is not subject to mould)
D.I. increment averaged over green and fallen = 2·28*0·55 = 1·25.
Hence D.I. at week 11 = 1·4 + 1·25 = 2·65.

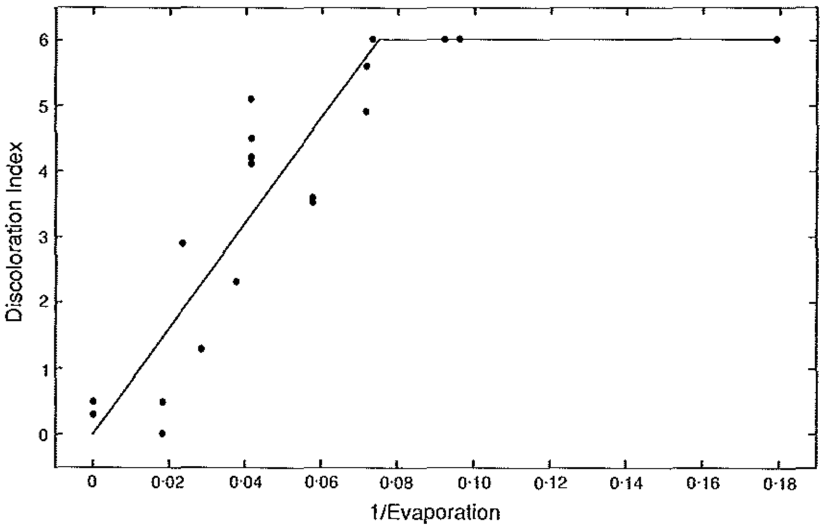

Fig. 1. Relationship between Discoloration Index, and cumulative inverse mean weekly Australian tank evaporation following rain events of 1·9 mm or more at Darwin, Adelaide River, Katherine, Townsville, and Woodstock.

Results

Before conducting the main simulation study, a test of the moulding prediction model was made. Fig. 2 shows a very favourable agreement of the observed and simulated development of discoloration, using the data from which regression equation 3 was derived.

Geographic variation in the average length of the Dry Season and the component periods of green leaf, sound dry leaf and spoiled dry leaf are depicted in Fig. 3.

For eight representative stations we have plotted in Fig. 4 the cumulative probability distributions of the occurrence of:

1. 75% legume leaf shed
2. Legume spoilage (D.I. = 5)
3. End of Dry Season (GOWK)

with the beginning of the Dry Season (STOPWK) as origin. Although our period of interest is the Dry Season we have shown the complete curves commencing from 75% legume leaf shed even when this occurs before STOPWK.

The mean values shown in Fig. 3 commence from STOPWK. The most conspicuous feature of variation is between stations in the east and those in the north-west. Dry seasons at stations 4, 5, 6, and 7 on the North Australian Plateaux; 3 in the Kimberley region; and 8, 9, and 10 in the Carpentaria Lowlands all have a high average duration of favourable conditions for preserving dry legume leaf litter. Stations closer to the east coast (11–28) and to the west coast (1,2) have longer average periods of spoiled dry legume.

The least risk of spoilage occurs at Darwin (5) and Adelaide River (6). At Adelaide River, in only 2 years in 10 does any spoilage occur, and in only 1 in 10 is the period of spoilage as long as 8 weeks. Dry seasons become progressively longer and the risk of spoilage increases gradually along transects south from Darwin (5) to Adelaide River (6), Katherine (7), and Newry (4) in the north-west, and from Weipa (10) to Mitchell River (9) and Normanton (8) in the east.

The distributions from Katherine (Fig. 4*a*) are typical of the most northern stations (Fig. 3, stations 3, 5, 7, 8, 9, 10). The Dry Season length (STOPWK to GOWK) ranges about 10 weeks each side of the mean (or median). Distributions of lengths of the sound legume period are very similar, i.e. in most years, dry legume remains unspoilt almost until the start

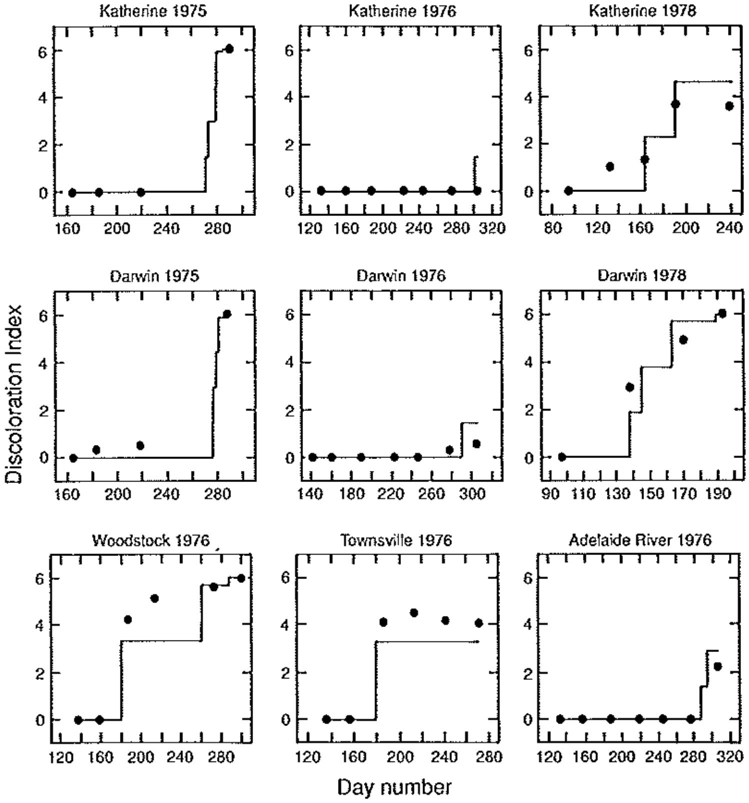

Fig. 2. Measured (•) and predicted (____) development of moulding.

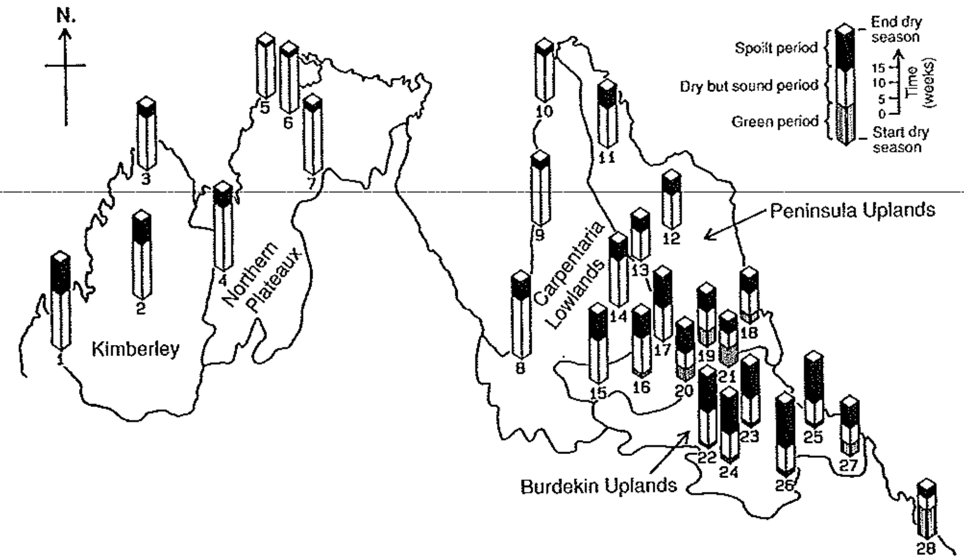

Fig. 3. Simulated states of legume leaf during the Dry Season at 28 stations (mean length of Dry Season, and mean times for which leaf is green, dry and sound, and spoilt). Stations identified in Table 1. Scale of map expanded in Cape York Peninsula; physiographic regions after Jennings and Mabbutt (1977).

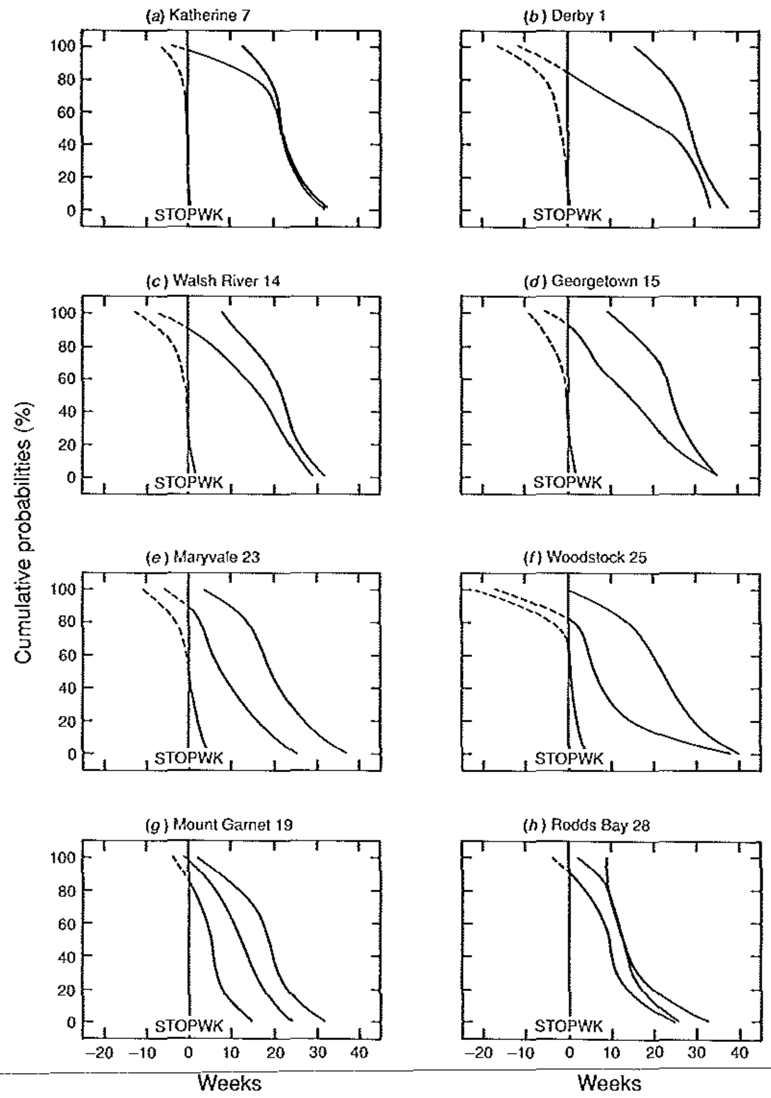

Fig. 4. Probability of exceeding a specified value of the time from the end of the Green Season of native grass pasture (STOPWK) until (left to right)
(1) 75% legume leaf has been shed,
(2) legume spoilage occurs (Discoloration Index ≥ 5),
(3) the end of the Dry Season (GOWK).
Because each curve is rank ordered independently, probabilities of differences cannot be read from the curves. However, areas between curves are proportional to mean differences. Differences betwen pairs of values (1) and (2) from the same season are given in Table 2.

of the next Green Season as per Fig. 4*a*. In 2 in 10 years at Katherine (Table 2) (and Mitchell River, not shown), spoilage occurs 4 or more weeks before this. This frequency increases to 4 in 10 at Newry and Normanton.

Accompanying the increase in duration of spoiled legume along a transect from Katherine (7) to Derby (1) (Fig. 3), is an increase in the year-to-year variation in length of this period. At Derby (1), spoilage does not occur 5 in 10 years (Table 2). Yet in the other 5 years, spoilage losses approach those stations with most severe losses in the entire region depicted in Fig. 3 (Table 2). There is a 2 in 10 chance of legume being spoilt by the time STOPWK occurs (Fig. 4*b*). The patterns of variation at Gibb River (2) and Newry (4) are intermediate to Derby and Katherine.

In the east, in addition to having dry season conditions generally less favourable to preservation of dry leaf, there is more variation among stations (Fig. 3). In addition, all eastern stations shown in Figs 4*c*–*h* have a much greater year-to-year variation in the duration of sound leaf than the stations which Katherine represents (4*b*). (In cumulative probability curves (Fig. 4), the greater the slope around the median, the greater the central tendency.)

Of the eastern stations, those in the north (11–14) have the most favourable conditions for a dry leaf strategy, although these are noticeably poorer than the majority of stations in

Table 2. Deciles of Weeks of Spoiled Legume Herbage

Maxima, descending deciles, and minima of weeks from date of dry legume spoilage (D.I. = 5) to the end of the Dry Season (GOWK)

	Katherine	Derby	Walsh R.	Georgetown	Maryvale	Woodstock	Mt Garnet	Rodd's Bay
Maximum	20·0	39·0	25·0	34·0	31·0	40·0	28·0	28·0
Decile 1	8·5	30·0	18·0	23·1	28·4	26·8	19·2	11·0
Decile 2	4·0	27·0	16·0	19·2	21·6	24·0	9·4	2·0
Decile 3	0·3	23·0	10·0	17·3	16·1	20·0	6·8	0·0
Decile 4	0·0	11·0	4·0	9·6	14·8	18·0	5·0	0·0
Median	0·0	0·0	0·0	6·0	10·0	16·0	5·0	0·0
Decile 6	0·0	0·0	0·0	3·0	3·0	12·8	1·6	0·0
Decile 7	0·0	0·0	0·0	0·0	0·0	7·2	0·0	0·0
Decile 8	0·0	0·0	0·0	0·0	0·0	2·4	0·0	0·0
Decile 9	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0
Minimum	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0

the north-west (Fig. 3). Climatic favourability for dry legume leaf declines progressively from this region to that comprised of stations 15–17 to that of 22–24 to 25–26. Probability distributions are shown for representatives from each of these regions in Figs 4*c*–*f*. There is an incremental progression in patterns from Walsh River (14) to Georgetown (15) to Maryvale (23) to Woodstock (25). Although the median Dry Season length of both Walsh River and Woodstock is 22 weeks, the range of variation at Woodstock is double that at Walsh River. As indicated by the areas between curves 1 and 2 in Figs 4*c*–*f*, the proportion of the Dry Season during which legume is sound declines progressively from Walsh River to Woodstock. A more precise estimate of the increase in risk of spoilage may be found from Table 2. Periods of spoilt legume of 7 weeks or longer occur in only 3 in 10 years at Walsh River, but in 8 of 10 years at Woodstock. In the entire region of Fig. 3, the risk of spoilage at Woodstock is exceeded only at Mirtna (26), and this only marginally (data not shown).

Although never great, the contribution of green legume (weeks to 75% leaf shed following STOPWK) increases progressively from Walsh River to Woodstock. Significant contribution by the legume in a green state occurs in only two regions (Fig. 3). One is in the south-east of the Peninsular Uplands and is represented by Mareeba (18), Mt Garnet (19), Meadowbank (20) and Cashmere (21) in Fig. 3. Of the legume contribution in the Dry Season at these stations, one third to one half is from green herbage. The second region where green legume could play a significant role is in the south-east, represented by Collinsville (27) and Rodd's Bay (28) in Fig. 3.

Probability distributions for Mt Garnet and Rodd's Bay are shown in Figs 4*g* and *h*. At Mt Garnet there is no green legume contribution 2 in 10 years; 5 in 10 years the green legume period following STOPWK exceeds 5 weeks and can reach 15 weeks. Legume either green or in a sound dry state spans the Dry Season 4 in 10 years, i.e. there is virtually no shortfall due to dry leaf spoilage (Table 2). In only 3 in 10 years is there a shortfall of 7 weeks or more (Table 2).

Rodd's Bay has a median Dry Season of only 14 weeks, although 2 in 10 are 20 weeks or longer (Fig. 4*h*). The primary mode of legume contribution here is as green herbage; in only 1 in 10 years is this negligible. In 5 in 10 years green legume is available for 10 weeks or longer into the Dry Season, with a maximum of 24. In only 2 in 10 years is there a shortfall of sound legume of 2 weeks or more, but as many as 28 weeks can occur.

Discussion

An earlier study of the climatic constraints to beef production in tropical Australia found that a large proportion of variation in cattle liveweights could be accounted for on native pastures, but not on pastures oversown with legumes. Variation in the nutritional value of perennial grass pastures could be simulated by simple models in which rain is never detrimental and is beneficial if temperatures are not too low (McCown 1981*a*; McCown *et al.* 1981*a*). This was not the case with pastures containing legume, where rain can be very detrimental. Models developed in this present series of papers make it possible to account for the deleterious consequences of rain in the dry season.

Although the scope of this study has been the effects of weather on the contribution by Caribbean stylo in the dry season, the contribution generally begins during the growing season. Dietary preference by cattle shifts from grass to legume about the time of rapid decline in grass quality, and decline in rates of weight gain is deferred (Gardener 1980). Just how long it is deferred is closely related to the central theme of this paper.

In Part III of this series (McCown and Wall 1989), we showed that leaching and moulding progressively reduce dry matter digestibility of Caribbean stylo leaf from above 70% to 50% when D.I. = 5. This means that our use in this present paper of time to D.I. = 5 to quantify preservation of leaf quality is conservative. The complexity of making comparisons of probability distributions among numerous stations seemed to rule out use of more than one quality indicator. We chose the point on the linear decline of digestibility in response to increased moulding which corresponded with drastic change in acceptability, i.e. spoilage. Although the data were not shown, the relativities between various stages in quality decline are such that use of any D.I. value results in much the same pattern of differences among stations as reported for D.I. = 5. Full D.I. time trend data for any station are obtainable from the authors.

Our simulations for Katherine and Rodd's Bay indicate that Caribbean stylo will provide the quality of herbage needed for the duration of most dry seasons (Fig. 4*a*, *h*; Table 2). At both locations major shortfalls in time when legume is unspoilt in relation to Dry Season duration are rare. At Katherine the dry season is long, and there is negligible contribution by legume in a green state, but dry legume rarely spoils. At Rodd's Bay, where the median dry season is much shorter, the simulated green leaf stage (from STOPWK to curve 1 in Fig. 4*h*), persists for much of the dry season in many years. Although conditions are frequently favourable for spoilage of dry leaf, as observed by Shaw (1961), in only 1 in 10 years of our simulations do these conditions occur when more than 75% of leaf has been shed and earlier than 2 weeks before GOWK (Table 2). Our models of leaf shedding and moulding were developed on data from a network of stations of which Townsville was the most southerly (McCown and Wall 1981). This means that simulations for Rodd's Bay are extrapolations and should be viewed with additional caution. It is possible, for example, that the long periods of green leaf in the dry season are overestimated owing to insufficient weighting of low temperature and omission of frost in our simulations. While quantitative accuracy is open to question, the relative differences between the simulated climate of Rodd's Bay and more northern stations conform to the observations of Norman (1970) and Shaw (1961), and to recent experience with *Stylosanthes scabra* in the region around Rodd's Bay. In the light of the importance of Shaw's results at Rodd's Bay to research further north, inclusion of this station (with the above caveat), seems justified as an aid to the interpretation of regional patterns.

The area with dry seasons favourable for retention of dry leaf quality in most years includes the stations in the north-west (Fig. 3, 1–7), and those in central and western Cape York Peninsula (8–16). Except for experimental results from Katherine, there is not much animal performance information in the north-west with which to test these simulation results. What little there is in the east comes from stations on the south-east margin. Since 1972, a large beef enterprise near Walsh River (Fig. 3, station 14; Fig. 4*c*), has profitably oversown large areas of native pasture, initially with Townsville stylo, later with Caribbean stylo (Edye and Gillard 1985). Assuming that the risks of spoilage are similar to the estimates for Walsh River in Table 2, this is the best evidence available that risks of this level or less are tolerable. At Georgetown (Fig. 3, station 15; Fig. 4*d*), large areas of Townsville stylo pastures are renowned for 'keeping cattle fat year-round' (Anning 1980); our simulations show that this observation could be made in about 40% of years.

Georgetown has a drier (and warmer) climate than Walsh River, and the impression of agriculturalists working in the region (C. P. Miller, personal communication) is that it has more favourable conditions for dry leaf preservation, yet our simulations show Georgetown to have a shortfall of unspoilt legume 3·4 weeks greater than Walsh River. We considered the possibility that our evaporation data for Walsh River were in error, as they were estimated using maps of monthly means, but found that even if the evaporation data were transposed between the two stations, shortfall was still one week longer at Georgetown than at Walsh River. The results of a more detailed analysis of the differences between these two stations support the simulation results:

(*a*) The net effect of the higher evaporation rates at Georgetown is to increase the shortfall by lengthening the Dry Season to 2·4 weeks longer than Walsh River.

(*b*) Georgetown receives more rain in the Dry Season than Walsh River.

Further details of this analysis are given in Appendix 1.

Resolution of this apparent discrepancy between experience and prediction requires more field information. While direct monitoring of animals or pastures for sufficiently long periods is rarely feasible, field measurements and observations which test model output for individual years can lead to improved calibration of the model and more realistic predictions.

The northern region with the highest densities of cattle is the Burdekin Uplands represented by Maryvale (Fig. 3, station 23; Fig. 4*e*) and Woodstock (Fig. 3, station 25; Fig. 4*f*). Cattle on native pastures here experience the greatest variation in dry season duration in northern Australia (Figs 4*e*, *f*; McCown 1981*b*). Although they have the best chance of dry season rain sufficient for significant 'green pick' of grass (McCown 1981*b*), they also have the greatest risk of legume spoilage (Figs 4*e*, *f*).

The Tablelands region, represented by stations 17–22 in Fig. 3, and Mount Garnet in Fig. 4 is too cool for good Caribbean stylo production, and stations 19–22 are prone to frost. Simulated dry season performance here serves more as a test of the climatic suitability for a dry leaf versus a green leaf strategy. A well-adapted, frost-resistant plant with the leaf shedding and nutritional characteristics of Caribbean stylo would be subject to about the same risk of moulding as at Walsh River (Table 2). However, the analysis indicates that in situtations where frost is not a problem, a green leaf strategy has more potential here than anywhere else in northern Australia. In fact, research on legumes for this region has tended toward strongly perennial types which retain leaf (Edye *et al.* 1975; Hunger *et al.* 1979).

Our climatic analysis provides a reliable basis for appraising the probable success of a dry leaf strategy. However, it may not be an equally reliable guide to the geography of a green leaf strategy. Where the analysis indicates an advantage for a green leaf strategy, such an advantage probably exists. However, at locations which the analysis indicates are well suited for preserving dry leaf, a green leaf strategy cannot be ruled out. To succeed, it requires a legume which can endure substantial water deficits without mass abscission of leaves and which is able to tap deep soil water; the soil must be able to store sufficient water and the wet season climate must reliably recharge this store. *Stylosanthes scabra* (Shrubby stylo) is a legume with the required attributes. At Katherine on a deep soil, it effectively depletes water to 4 m, 1 m deeper than Caribbean stylo (Wall and McCown, unpublished data). At this same location, Winter, Mott and McLean (unpublished data) found that cattle annual liveweight gain increments on pastures of Seca Shrubby stylo, on which leaves are retained and remain green, and pastures of Verano Caribbean stylo, which shed their leaves, did not differ significantly in four years of study. However, patterns within seasons differed markedly, Caribbean stylo recording the higher weight gains during the wet season and early dry season, and Shrubby stylo recording the lower weight loss in the late dry season, and the complementary features of the two legumes were evident. It would seem that, except in those areas too cool for Caribbean stylo, sowing Caribbean and Shrubby stylo mixtures may serve to spread the dry season nutritional risks. However, at those locations favourable for a dry leaf strategy, marginal benefits of including the deep rooting legume can be expected to depend on site microhydrology as influenced by tree killing as well as soil profile characteristics and climate.

The progress made in this research in dealing with ambiguous effects of rain in the dry season is adequate for interpreting climatic regions, as we have done. These same models have the potential to improve simulation of animal production in mixed grass-legume pastures in this region. However, realization of this potential awaits the development of models which better predict yield of grass and legume components and the interactions between components, including the contribution to soil N by the legume and the effect of this and other factors on botanical composition.

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Appendix 1. Detailed comparison of Georgetown and Walsh River simulations.

Georgetown has a mean annual rainfall of 813 mm, compared with Walsh River 893 mm, and evaporation 1930 mm, compared with Walsh River 1760 mm. Higher evaporation has two opposing effects on the period of sound legume leaf. It increases the rate of soil water loss, causing leaf to be shed earlier, when there is a higher probability of rain, but it also reduces wet time and slows the moulding process, and the net effect at Georgetown is slight. However, even though the time to spoilage is not reduced by greater evaporation, the lengthening of the Dry Season due to faster soil water loss means that the shortfall is increased.

exchanging the evaporation data between the two stations reduced the difference in Dry Season lengths to nil, so about half this difference is due to Georgetown's higher evaporation and the remainder to rainfall differences.

The spoilt time at Georgetown is potentially 2·4 weeks longer than at Walsh River because of the longer Dry Season. In addition, spoilage at Georgetown occurs on average about one week sooner. Analysis of the rainfall records for the period following leaf shedding shows that in fact falls of 2 mm or more are then more frequent at Georgetown, even though their amount and distribution cannot maintain native pasture growth.