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Aust. J. Agric. Res., 1981, 32, 575–87

The Influence of Weather on the Quality of Tropical Legume Pasture during the Dry Season in Northern Australia. I Trends in Sward Structure and Moulding of Standing Hay at Three Locations

R. L. McCown[A], *B. H. Wall*[A], *and P. G. Harrison*[B]

[A]Division of Tropical Crops and Pastures, CSIRO, Townsville, Qld 4814.
[B] Northern Territory Department of Primary Production, Darwin, N.T. 5790.

Abstract

In seasonally dry tropical climates, animal production is severely constrained during the dry season by the low nutritive value of dry grass forage. Introduction of a legume such as Caribbean stylo can provide a valuable alternative forage during this period, mainly in the form of leaf litter and accompanying seed. The actual contribution of dry legume is closely dependent on its moisture regimen, which determines the degree of mould growth, an important palatability factor. This paper reports a 2-year study conducted at Katherine, Darwin and Townsville of the environmental control of both the timing and rate of leaf shed and of the subsequent moulding of leaf litter. At Katherine and Darwin, leaf was shed early and rapidly; at Townsville, much lower evaporation rates and small rainfalls delayed and prolonged leaf shed by several weeks. The data provide a model for predicting leaf shed by using standard weather data to aid the assessment of the risk of forage damage by precipitation.

Introduction

The introduction of a legume into native grass pastures in the seasonally dry tropical region of Australia results in increased production of beef cattle. This was first demonstrated with the annual, Townsville stylo (*Stylosanthes humilis*) (Shaw and Norman 1970; Woods 1970; Winks *et al.* 1974; Gillard 1979), and more recently with the short-lived perennial Caribbean stylo, *S. hamata* cv. Verano (Gardener 1980; Gillard *et al.* 1980). There are, however, very large and important differences within the region in the contribution of the legume to cattle performance in the dry season. Shaw and Norman (1970) contrasted two situations which they suggested represent the extremes. Cattle at Katherine 'with almost complete absence of rain and dew in the dry season' gain weight on standing hay of Townsville stylo. At Rodd's Bay, in coastal Queensland, the matured Townsville stylo rapidly deteriorates 'under the influence of dew and light falls of rain', and cattle lose weight.

Recent animal production studies in the region indicate that the main effect of moisture on dry legume is on its palatability. Cattle grazing dry Caribbean stylo pasture in the dry season at Katherine prefer leaf, which they lick off the ground, to stems or dry grass. However, leaf consumption drops abruptly after rainfall (R. McLean, personal communication), but in the Katherine environment, rain rarely occurs during the dry seasons. In the more humid environment of subcoastal northern Queensland where rainless dry seasons are rare, Gardener (1980) found that dry Caribbean stylo leaf was never an important dietary component during the 2 years of study.

This series of papers reports the results of two experiments designed to quantify the effects of precipitation on the quality of naturally desiccated Caribbean stylo 'standing hay'. This includes an analysis of the relative importance of dew and rainfall on moulding, and of the importance of moulding compared with leaching. The results are then used with weather records to assess the variation across the tropical beef-producing region of Australia in the risk of significant losses of legume quality. Since moisture damages only dry tissue, the time of transformation of green leaf to dry leaf litter of this deciduous legume must be known to predict weather damage. This paper reports a study of the trends in leaf senescence and moulding of litter in relation to the weather during two dry seasons at three locations selected to cover much of range in climate of the region.

Locations, Materials and Methods

The three locations were the CSIRO Research Station at Katherine, N.T.; Berrimah Experiment Farm, Darwin, N.T.; and the CSIRO Davies Laboratory, Townsville, Qld. Although all three stations experience a highly seasonal rainfall distribution, there are substantial differences in dry season climate. The median rainfall at Katherine during May–August indicates a reliably long dry period, whereas at Darwin, the median rainfall during this period is somewhat higher and, at Townsville, is considerably higher (Table 1). Mean relative humidity at 1500 hours is much lower at Katherine than the other stations while pan evaporation at Townsville is much lower than at the other two stations (Table 1).

Table 1. Climatic averages for the three experimental sites

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
						Median rainfall (mm)							
Katherine	202	193	136	10	0	0	0	0	0	16	70	177	966
Darwin	457	397	355	41	9	0	0	1	12	81	100	291	1723
Townsville	221	301	210	32	18	11	2	2	2	13	27	62	1117
						Mean relative humidity at 1500 hours (%)							
Katherine	52	54	49	37	34	31	27	24	23	27	32	43	36
Darwin	68	74	69	53	47	45	40	47	49	55	57	65	56
Townsville	62	66	63	57	54	52	47	51	51	52	56	58	56
						Mean monthly pan evaporation (cm)							
Katherine	21	18	18	20	21	18	19	22	26	29	28	25	265
Darwin	19	16	20	18	21	21	21	24	24	29	26	21	260
Townsville	19	15	16	13	12	10	12	13	17	20	22	25	194

Swards of Caribbean stylo were sown in January 1978. At Katherine and Darwin, on old agricultural areas with a long history of single superphosphate fertilizations, 100 kg ha^{-1} single superphosphate was applied at sowing; the more recently developed Townsville site received 300 kg ha^{-1} single superphosphate. Although cultural procedures differed among sites, dense, healthy, nearly weed-free swards were achieved. In late February or early March, half the area at each site was mown at 10 cm with a reciprocating mower and the cut material removed. At both Katherine and Darwin this resulted in two main plots, hereafter referred to as 'unmown' or 'mown'. The sward was so divided to ensure against either having a low-yielding sward owing to poor growing conditions following mowing, or lodging of the unmown sward. At Townsville the unmown plot lodged severely and only the mown plot was studied. Although at the other two locations both treatments were studied, the results reported here are mainly from the higher yielding unmown plots. At Katherine, 2 weeks after mowing, an unmeasured amount of supplementary irrigation was applied to the mown plot in an attempt to get as much regrowth as possible before temperatures dropped.

Each main plot measured 9 m by 15 m. Five areas 6 m by 2 m were reserved for collection of fallen leaf. In mid-March a 'row' of plants was removed to allow the insertion of a tray into the sward from the edge of the plot. Each tray was a 2 m length of 50 mm diameter aluminium tubing from which one half had been cut away longitudinally, with the remaining intact 1 m length serving as a handle. Tape was placed across the open end of the tray section. A track made from angle iron was placed on the soil to facilitate easy and reproducible placement and removal with minimal disturbance of plants.

To simulate the effects of grazing animals walking through a sward and dislodging senesced leaflets, the sward was disturbed at weekly intervals by 'brushing' vigorously with a length of 50 mm diameter aluminium tubing. Samples containing leaf, inflorescence, seed and shed-leaf segments of stem were collected from the trays at intervals varying from 1 to 7 days, depending on the rate of shed and the risk of rain. The five samples from each main plot were bulked for periods of about 1 week. Air-dry weights were obtained for the leaf fraction only and expressed as a percentage of the total leaf in the sward.

Measurements of biomass distribution were made at nominal monthly intervals. Eight quadrats (50 cm by 50 cm) were cut at ground level, two at random in each quarter of each main plot. The 'average' height of the vegetation was recorded before placement of the quadrat. After cutting, the material was carefully placed in large bags and transferred to the laboratory for subsampling. In the laboratory, each sample was first placed in a large bin and shaken to remove any senesced leaf, and then laid on a bench marked at 20 cm intervals and positioned to recreate the field height. It was then cut into 20 cm vertical strata, subsampled for the estimation of the proportion of leaf and stem, and all fractions were oven dried at 70°C and weighed.

Two quadrats, 11 cm by 11 cm, were used to sample litter within each 50 cm by 50 cm quadrat. An 'upper' litter fraction was generally distinct from a more decomposed and/or discoloured 'lower' fraction, and each was collected separately. Leaf that was judged (by its colour) to have fallen during harvest was separated from 'upper' litter, and all fractions were oven dried and weighed. The dry weight of the freshly fallen leaf fraction, after appropriate weighting for differences in sample areas, was added to that of the senesced leaf shaken from standing biomass samples, and reported as 'leaf dislodged during harvest'. The colour of the litter fractions was coded with the Munsell Soil Colour system using the value and chroma of the 10YR hue chart.

Periodically, leaf samples from each litter and freshly fallen fraction were collected for isolation and identification of the fungi present. The results of this aspect of the study are reported elsewhere (Shipton *et al.* 1981).

In order to assess trends in the internal water status of the swards, leaf relative water content (RWC) at 1400 hours was measured at weekly intervals. A sample of *c.* 20 central leaflets of the youngest fully expanded leaves was collected along three transects in each main plot. The method of determination was that of Barrs and Weatherley (1962).

A rain gauge was read daily at each site. In each main plot a thermohygrograph was placed on the ground in a 'hole' cut in the sward. A polystyrene cover 2 cm thick shielded the instrument from direct radiation. Calibration of recorders was checked weekly.

In 1979 an abbreviated study was conducted at Katherine and Townsville in which only leaf shedding and RWC measurements were made on unmown swards. Methods were identical to those in 1978.

On completion of the study in 1978 at Katherine and Darwin, oesophogeal fistulated (O.F.) cattle were grazed on the experimental areas. At Katherine three animals were used to sample for a period in the early morning and late afternoon on 3 consecutive days, 26–28 September. At Darwin three animals were used to sample in one period in each of 2 days on 4 and 6 October. Cattle were enclosed on the area for 2 days before the first sampling and were removed upon completion of sampling. Botanical composition of the samples taken from the O.F. cattle were determined by the method of Van Dyne and Heady (1965); one person analysed all the samples. The soil water balance at each site was simulated for each location and year by using the method described by McCown (1981), except that the 'crop coefficient' was assumed to be 1·0. Soil water storage capacity was assumed to be 150 mm at all sites. Rainfall data were those measured at the site; Class A pan evaporation data at Katherine and Townsville were collected at meteorological stations a few hundred metres away, while at Darwin these data came from the Darwin airport 3 km away. A weekly Water Index was calculated as (actual water use)/(potential water use); the Growth Index (G.I.) was calculated as the product of the Water Index and a Tem-

Table 2. The frequency of occurrence of various combinations of Value and Chroma of the 10YR Munsell Soil Colour Chart for 42 legume leaf samples; an assigned Discoloration Index

Value	Chroma 6	Chroma 5	Chroma 4	Chroma 3	Chroma 2	Discoloration Index
7·0	1	7	4			0
6·5	(Yellow) 1	1	(Yellowish brown) 3			1
6·0		1	4	1		2
5·5			2	(Brown) 3	(Greyish brown) 1	3
5·0			1	4	1	4
4·5					2	5
4·0				(Dark brown) 2	(Dark greyish brown) 1	6
3·5					2	7

perature Index. The Temperature Index was that used by McCown (1981) and weekly mean daily temperatures calculated from monthly means (Australia, Bureau of Meteorology 1975) were used as input.

Results

Quantification of mouldiness

The frequencies of value and chroma for 42 samples of leaf are shown in Table 2. There is a high correlation between the two parameters, with samples varying between the extremes of yellow (7/6) to dark greyish brown (3·5/2). This pattern suggests that a single parameter scale should be defined, with zero referenced to the colour of leaves totally senesced but before any mould discoloration. The state of general mouldiness of samples is hereafter expressed by the Discoloration Index (D.I.) of Table 2.

Table 3. Structure and composition ($g\ m^{-2}$) of standing crop and leaf litter at Katherine
n.d., not determined

Harvest no.:	1		2		3		4		5	
Date:	5 Apr.		13 May		14 June		11 July		28 Aug.	
	Leaf	Stem	Leaf	Stem	Leaf	Stem	Leaf	Stem	Leaf	Stem
Crop strata (cm)										
60–80			25	38	15	34	4	22	0	n.d.
40–60	107	89	66	167	37	153	14	130	0	n.d.
20–40	88	177	19	173	8	172	0	171	0	n.d.
0–20	25	157	0	148	0	168	0	168	0	n.d.
Total	220	423	110	526	60	527	18	491	0	—
Leaf dislodged during harvest	n.d.		66		58		37		10	
Upper leaf litter	0		81 ± 15[A]		133 ± 20		125 ± 26		132 ± 32	
D.I.	—		1·0		1·3		3·6		3·5	
Lower leaf litter	n.d.		23 ± 13		24 ± 13		45 ± 20		29 ± 17	
D.I.	—		6·0		6·0		6·0		6·0	
Total crop + litter	220	423	280	526	275	527	225	491	171	—
Rainfall[B] (mm)	—		0		2		12		0	

[A] Range is 95% confidence limits.
[B] Total rainfall since last harvest.

Time trends in the quantity and location of leaf

Katherine

The total yield of crop plus litter of the unmown sward at Katherine reached its peak (*c.* 800 $g\ m^{-2}$) in May (Table 3). Green leaf yield was maximal on, or soon after, Harvest 1 (5 April). Although the G.I. declined rapidly after this time (Fig. 1*a*), there had been some height increase by Harvest 2 (13 May) (Table 3). A peak leaf yield of 250 ± 25 g m^{-2} is suggested by the comparison of the total of green leaf and litter leaf of later harvests. Considerable leaf had been shed from the lower canopy strata by Harvest 2 and this continued with each successive harvest interval.

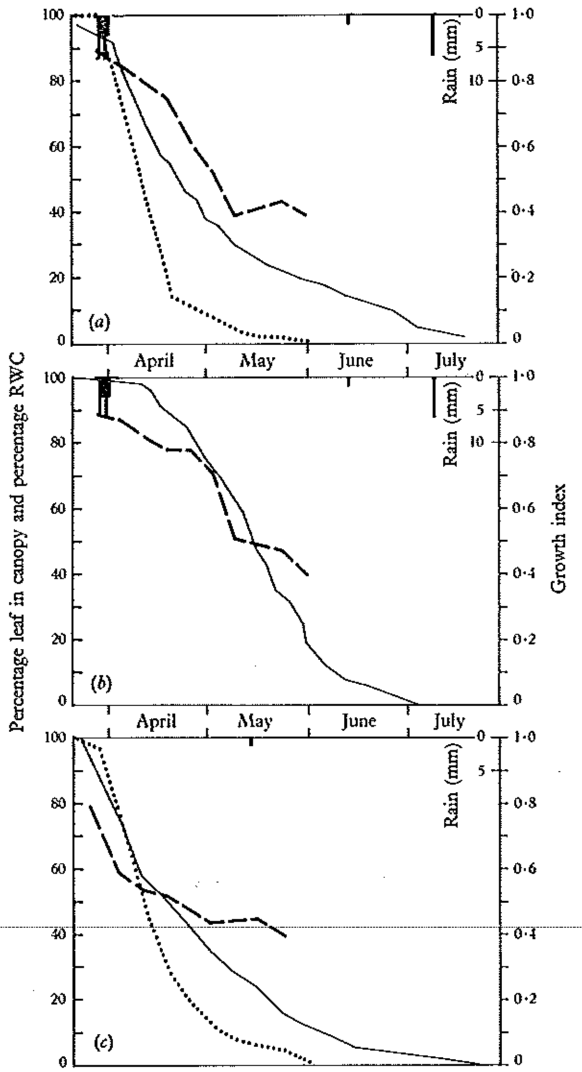

Fig. 1. Trends in percentage of leaf remaining in the crop canopy (——), G.I. (····), and RWC (– – –) at Katherine. Daily rainfall is shown as a histogram. (*a*) 1978 unmown. (*b*) 1978 mown; irrigated in March. (*c*) 1979 unmown.

The time trends of leaf shed are seen more clearly in Fig. 1*a*. Rapid leaf fall began shortly after Harvest 1 and continued for about 1 month, at which time 70% of leaf had fallen. The remaining leaf was shed at about one third of this rate. Coincident with the initiation of rapid leaf shed was a steep decline in both the leaf RWC and G.I. When 70% of the leaf had been shed, RWC had dropped to 39% and G.I. to 0·05.

The supplementary irrigation of the mown plot resulted in prolonged favourable plant water status and delayed leaf shed (Fig. 1*b*). As on the unmown plot, the date of 70% leaf shed coincided with the decline of RWC to 40%. But for the delay in decline in RWC, because of a small rainfall on 14 May, the date of 70% leaf shed in 1979 would have also coincided with a RWC very close to 40% (Fig. 1*c*).

Darwin

Total crop plus litter dry matter yield of the unmown sward at Darwin was over 1100 g m^{-2} (Table 4). Peak green leaf yield of about 230 g was reached by Harvest 1 (8 April) and a large proportion of the leaves had been shed by Harvest 2 (18 May). Since leaf fall measurements did not begin until late April, well after the start of rapid leaf shed, litter yield at Harvest 2 has been used to estimate the total leaf quantity for calculation of the percentage leaf shed values in Fig. 2. (The change in the quantity of upper litter between Harvests 1 and 2 agrees very closely with the change in green leaf in the canopy.) Extrapolation of the percentage leaf-shed curve was guided by the general relations between leaf shed and the two environmental variables, RWC and G.I. in Fig. 1. In both unmown and mown treatments at Darwin, G.I. and RWC declined even more rapidly (Figs 2*a* and *b*) than at Katherine (Fig. 1*a*). By the time RWC had dropped to close to 40%, 38% (unmown) and 33% (mown) of leaf had been shed. At this time G.I. had reached about 0·05. Small amounts of rain subsequently produced slight recoveries in G.I. and RWC, but with a negligible effect on leaf shed rates.

Table 4. Structure and composition (g m^{-2}) of standing crop and leaf litter at Darwin

n.d., not determined

Harvest no.:	1		2		3		4	
Date:	8 Apr.		18 May		19 June		12 July	
	Leaf	Stem	Leaf	Stem	Leaf	Stem	Leaf	Stem
Crop strata (cm)								
60–80	52	52	38	68	17	122	24	93
40–60	139	232	37	229	14	246	31	241
20–40	38	266	6	182	0	239	0	269
0–20	0	250	0	196	0	228	0	231
Total	229	800	81	675	31	835	55	834
Leaf dislodged during harvest	n.d.		30		20		17	
Upper leaf litter	0		116 ± 25[A]		149 ± 31		135 ± 22	
D.I.	—		2·9		4·9		6·0	
Lower leaf litter	92 ± 28		80 ± 13		74 ± 20		65 ± 15	
D.I.	7·0		7·0		7·0		7·0	
Total crop + litter	321	800	307	675	274	835	272	834
Rainfall[B] (mm)	—		4		16		12	

[A] Range is 95% confidence limits.
[B] Total rainfall since last harvest.

Townsville

At Townsville, the maximum crop and litter dry matter yield of 700 g m^{-2} was not reached until Harvest 3 (2 June), although leaf yield reached a maximum of

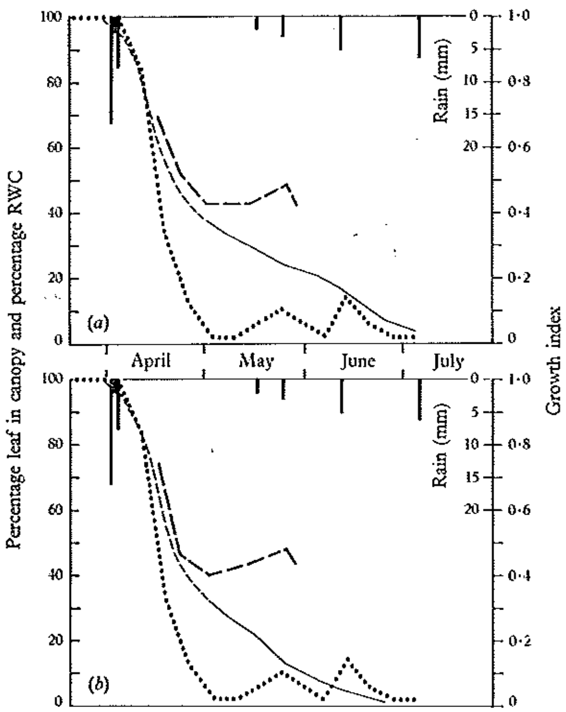

Fig. 2. Trends in percentage of leaf remaining in the crop canopy (——), G.I. (····) and RWC (– – –) at Darwin. Daily rainfall is shown as a histogram. (*a*) 1978 unmown. (*b*) 1978 mown.

Table 5. Structure and composition (g m^{-2}) of standing crop and leaf litter at Townsville
n.d., not determined

Harvest no.:	1		2		3		4		5	
Date:	4 Apr.		1 May		2 June		4 July		2 Aug.	
	Leaf	Stem	Leaf	Stem	Leaf	Stem	Leaf	Stem	Leaf	Stem
Crop strata (cm)										
40–60	31	17	26	26	4	19	1	10	0	0
20–40	71	59	70	167	64	275	10	202	2	147
0–20	50	120	5	188	16	266	2	320	0	343
Total	152	196	101	381	84	560	13	532	2	490
Leaf dislodged during harvest	n.d.		7		8		0		0	
Upper leaf litter	0		10 ± 5[A]		15 ± 6		0		0	
D.I.	—		2·0		2·0		—		—	
Lower leaf litter	n.d.		21 ± 6		42 ± 8		130 ± 44		130 ± 39	
D.I.	—		4·0		5·0		5·0		6·0	
Total crop + litter	152	196	139	381	149	560	143	532	132	490
Rainfall[B] (mm)	—		26		26		11		17	

[A] Range is 95% confidence limits.
[B] Total rainfall since last harvest.

150 g m^{-2} by Harvest 1 (4 April) (Table 5). The water regimen deteriorated much less rapidly there than at Katherine and Darwin. This is most readily seen by comparing trends in the Water Index at Townsville (Fig. 3*a*) with those of the G.I. at Katherine and Darwin (Figs 1*a* and 2*a*). At Townsville, suboptimal temperatures contributed to lowering the G.I., as indicated by the discrepancy between the G.I. and Water Index curves (Figs 3*a* and *b*); at the other stations the effect of low temperatures on the G.I. was negligible. The slower decline in the Water Index at Townsville was due to the higher rainfall and lower potential evaporation rates compared with the other stations (Table 1).

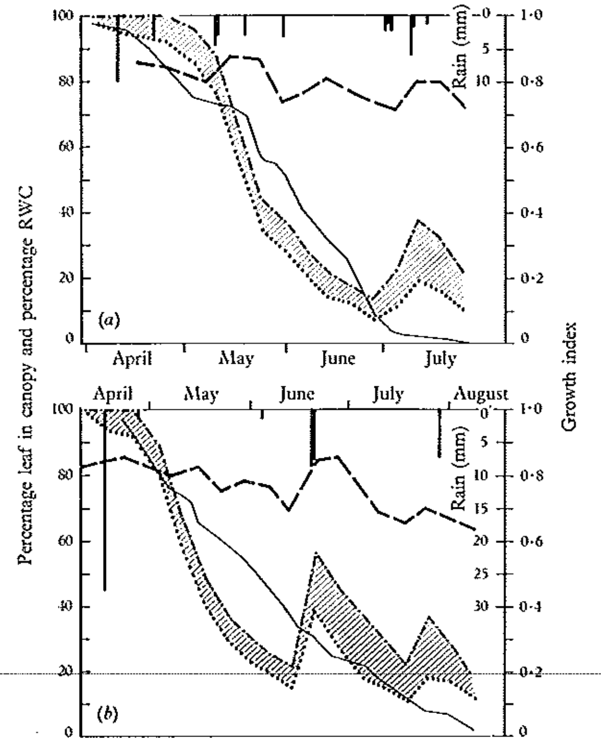

Fig. 3. Trends in percentage of leaf remaining in the crop canopy (——), G.I. (···), Water Index (—·—) and leaf RWC (– – –) at Townsville. Daily rainfall is shown as a histogram. (*a*) 1978 mown. (*b*) 1979 mown. Shading between G.I. and Water Index curves shows the amount that G.I. was reduced by suboptimal temperatures.

In 1978 leaf shedding began as the G.I. and RWC began to decline in mid-April (Fig. 3*a*). Minimum G.I. was not reached until late June, at which time over 90% of leaf had been shed. The time of occurrence of a minimum RWC was much less distinct than at Katherine and Darwin, and RWC never dropped below 72%. Patterns of leaf shed, G.I., and RWC in 1979 (Fig. 3*b*) were similar to those in 1978, with later initiation and slower rate of 'haying off' of pastures in Townsville relative to Katherine and Darwin. Again, minimum RWC was much higher than at Katherine and Darwin. Substantial rain at the time of 70% leaf shedding appeared to have little effect on leaf shedding rate.

Time trends in litter quality

Katherine

The lower layer of litter at Katherine was a thin mat of partially decomposed leaflets which presumably formed in late March and early April, when the surface soil was moist. Its identity and quantity did not change appreciably after Harvest 2 (Table 3). Leaf shed between Harvests 1 and 2 formed an unconsolidated layer of strongly curled leaves with a yellowish brown colour (Discoloration Index (D.I.) = 0). This layer became thicker between Harvests 2 and 3 as more leaf was shed, and the D.I. increased to 1·3 because of 2 mm of rain. Twelve mm of rain before Harvest 4 resulted in a D.I. of 3·6 in the upper litter-layer. The colour of this material did not change further in the rainless interval between Harvest 4 and 5.

One rainfall of 4·6 mm occurred between Harvest 5 and diet sampling, and raised the D.I. to 4. Oesophogeal fistulated (O.F.) cattle were initially reluctant to eat leaf

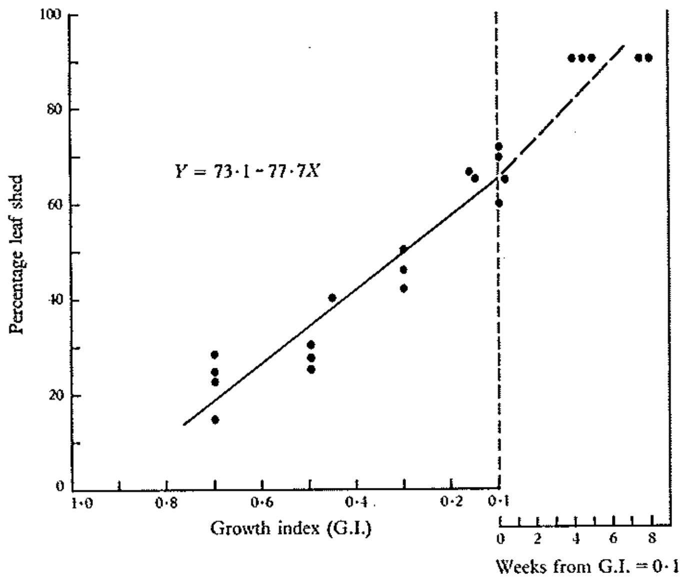

Fig. 4. The dependence of cumulative leaf shed on the G.I. down to 0·1 (——) and on the time below 0·1 (– – –).

litter except on a small area which had been protected from all rainfalls and had no increase in D.I. (Shipton *et al.* 1981). After the first day, however, all animals were licking up leaf litter from rain-affected areas, as indicated by the high leaf content of the diet samples (Table 6).

Darwin

At Darwin, a layer of partially decomposed leaflets was present at the time of the first harvest (Table 4). Between harvests 1 and 2, 70% of the canopy leaf was shed; 4 mm of rain just before Harvest 2 (Fig. 2) caused a rise in the D.I. to 2·9. During the following harvest interval 16 mm rain fell, raising the D.I. to 4·9. D.I. rose further to 6·0 during the next harvest interval in response to a further 12 mm rain.

A further 8 mm rain fell before diet sampling. The O.F. cattle were so reluctant to eat this pasture, even after being given 5 days to adapt, that it was impossible to obtain diet samples of the desired amount; the cattle lost condition and had to be removed after this period. Analysis of the material that was obtained indicates that stem was less objectionable than leaf (Table 6).

Townsville

At Townsville there was never much litter that was not mouldy (Table 5). Sufficient rain fell in every harvest interval to mould any new upper-litter fraction.

Prediction of leaf shedding

At all three locations in this study there is an obvious correlation between leaf shedding and G.I. (Figs 1, 2 and 3). In order to achieve the main objective of this research programme, i.e. to predict moulding and leaching losses from standard weather records, it is essential that these data be synthesized to provide a general relationship which can be used for predicting the period of post-shed vulnerability of leaf. In Fig. 4 values of cumulative leaf shed and corresponding G.I. were drawn from Figs 1, 2 and 3 for nominal G.I. values of 0·7, 0·5, 0·3 and 0·1. A straight line was fitted which accounted for 91% of the variance and whose equation was $Y = 73\cdot1 - 77\cdot7X$. However, when the G.I. is 0·1 and approaching its lower limit of zero, there is *c.* 30% of leaf still green. To overcome this problem an extension to the range of the independent variable G.I. has been made in Fig. 4 by counting the weeks since G.I. equalled 0·1.

Table 6. Botanical composition of cattle diet samples

	Leaf	Stem	Seed	Inflorescence	Other
Katherine					
26–28 Sept.	49	43	4	2	2
Darwin					
4–6 Oct.	21	75	1	1	2

Discussion

Of the many *Stylosanthes* genotypes introduced and evaluated in the Australian tropics in recent years, *S. hamata* cv. Verano (Caribbean stylo) is one of the most promising. It is high yielding, easy to establish, seeds prolifically, competes strongly, and provides nutritious feed for cattle (Edye *et al.* 1975; Torssell *et al.* 1976; Gardener 1980). As well as several other herbaceous species, Caribbean stylo is strongly deciduous, whereas the members of a group of shrub types, e.g. *S. scabra*, retain a large proportion of leaf in a green state throughout the dry season. The problem caused by the vulnerability of dry feed to moulding in the event of winter rain is illustrated by the present study. In 1978, even at Katherine and Darwin, which normally have reliable rainless dry seasons, standing hay moulded. Beef production studies at Katherine since 1974 have shown that, in the absence of winter rain, cattle performance on Caribbean stylo is as good as or better than that on stylos that remain green; large abrupt weight losses have occurred following rain (W. H. Winter, personal communication). Clearly, the effect of climate on leaf shed and moulding is one determinant of the scope of this plant for pasture improvement.

This study has focused on the fate of only the leaf component of Caribbean stylo forage. This decision was based on several considerations. Firstly, its leaf has a much higher nutritive value than stem, e.g. percentage nitrogen of dry leaf is 3–4 times higher than stem (Gardener 1980). Secondly, although seed is of much higher nutritive value, there is much less of it and since it is mixed with leaf litter during most of the dry season, the fate of the seed is coupled to that of the leaf. Seed is consumed when leaf litter is licked off the ground; if rain destroys leaf litter palatability, seed consumption ceases (M. J. Playne and R. L. McCown, unpublished data). Thirdly, leaf is not only the most valuable dry component, but it is also the most vulnerable to the effects of moisture. Whereas on unmoulded pasture cattle consume mainly leaf, after serious moulding cattle prefer stem to leaf (Table 6; Gardener 1980).

For predicting periods when legume forage is vulnerable to damage by rainfall, the simple concept of leaves moving from a green pool to a dry litter pool as the plants undergo progressive water stress appears adequate. In reality, however, the size of the green leaf pool is a function of the rate of new leaf production and the rate of senescence of old leaves; the size of the litter-leaf pool is a function of the rate of senescence and the rate of decomposition. The results from Katherine and Darwin indicate that water stress had a very dramatic effect on both growth and senescence (Figs 1 and 2). At Townsville, there is less evidence of a strong effect of moisture stress on senescence rates; the onset of stress was much more gradual and stress was generally much less severe (Fig. 3). Leaf shedding at Townsville was more gradual and steadier than at Katherine and Darwin, and it is possible that, although leaf production ceased with the decline in RWC, leaf senescence rates were largely unaffected by the moderate water stress. Wilson and 't Mannetje (1978) found that leaves of two tropical grasses senesced even less rapidly in the dry season than in the wet.

Guilbert *et al.* (1931) found that the most important effect of rainfall on dry medic in the Mediterranean annual pastures of California was that of leaching. Although rain followed by warm humid weather caused mould growth, the feed usually dried quickly after rain, with little or no mould growth. In our study, moulding occurred after only small amounts of rain. It is possible that rain, particularly in spring, may leach important amounts of nutrients from leaf litter, but this is of little consequence if an earlier non-leaching amount of rainfall has rendered it unpalatable owing to moulding.

The implications for animal production of rain on dry legume in this region are closely linked to its effect on associated perennial grass. Cattle prefer young green grass to any other forage component (Gardener 1980), and a 50 mm fall of rain on dry grass pasture can result in sufficient green grass growth to change cattle weight loss to weight gain (McCown 1981). Hence winter rainfall, sufficient to do serious leaching damage to dry legume, can be expected to have a compensatory effect via the grass. Conceivably, the worst event is rainfall sufficient to mould the legume but not enough to produce significant grass growth. This was undoubtedly the case at Katherine and Darwin in 1978, and in 1974 in the study of Gardener (1980).

Development decisions, especially in an economic environment of rising costs and unstable prices, would be substantially aided by an improved description of the geographic variation in the benefits and risks associated with pasture improvement using legumes. The demonstration here that the key processes which determine quality, i.e. leaf shed and moulding of litter, are closely coupled to attributes of the agricultural climate that can be readily derived from standard meteorological data, is a first step toward this objective. The next paper in this series quantifies the relationship between moulding and moisture.

Acknowledgments

The capable technical assistance of W. Beyer, D. Tolson and D. Hanson is gratefully acknowledged.

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Manuscript received 9 January 1981, accepted 17 February 1981