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The Influence of Weather on the Quality of Tropical Legume Pasture during the Dry Season in Northern Australia. II* Moulding of Standing Hay in Relation to Rain and Dew

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Abstract

Naturally desiccated legume pasture is valuable forage in the dry season but is very vulnerable to moulding, which drastically reduces its acceptability to cattle. At a network of sites in the wet–dry tropics of Australia, trends in mouldiness of standard leaf 'litter' samples were monitored in relation to rain, dew, and rates of drying.

Although heavy dews occurred frequently at some sites, only the immediate top layer of fallen leaf moulded. This had a very small effect on the mouldiness of the bulk sample. Appreciable moulding occurred only after at least 2 mm rain, but in some cases there was no mould growth after over 10 mm rain; the amount of rain accounted for only 23% of the variation in mouldiness. The duration of wetness of the leaf litter, as indicated by the duration of >95% relative humidity 10 cm above the ground after rain, accounted for 91% of the variation in mouldiness. At the more humid sites, material which was exposed for several weeks before rain moulded more rapidly after rain than did recently exposed material, even though at the time of rain there were no visible differences.

Differences in causation of moulding of conventional hay and of 'standing hay' are discussed.

Introduction

Dry legume 'standing hay' can be a valuable forage for beef cattle in the dry season in tropical Australia (Norman 1970). The most important component of this hay is the leaf, which sheds as the sward desiccates and is licked up, along with seed, by the grazing animal. This forage is, however, extremely vulnerable to moulding. Regional variation in this type of quality loss is widely recognized and has been attributed to differences in dry-season dew and to small falls of rain (Shaw and Norman 1970; Winks *et al.* 1974). Even a few millimetres of rain can promote fungal growth which drastically reduces the acceptability of forage to grazing cattle (McCown *et al.* 1981).

In view of the considerable capital cost of developing leguminous pastures, and the additional opportunity cost of managing wet-season grazing to conserve a large proportion of the forage for use in the dry season, a quantitative assessment of the geographic variation in the risks of spoilage would clearly assist development planning. This is the aim of this series of papers. The first paper focused on the process that renders the pasture vulnerable to the adverse effects of moisture. Leaf of Caribbean stylo *Stylosanthes hamata* cv. Verano was found to senesce and shed in response to soil moisture depletion, and time trends could be related to the decline in a simple

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growth index generated from standard weather data (McCown *et al.* 1981). This paper examines the effects of rain, dew, and high humidity on the moulding of dry, Caribbean stylo leaf litter, the 'lying down' portion of 'standing hay'.

Locations, Materials and Methods

Experiment 1

In early April 1975, and again in 1976, swards of Caribbean stylo were cut and the material air dried rapidly under cover. Leafy material was then stripped from plants to produce a mixture of leaf, petioles and fine stem. Aliquots of this simulated 'litter', equivalent to 10 g air-dry weight, were packaged in preparation for exposure at various sites.

In both 1975 and 1976, 'litter' samples were exposed in the Northern Territory at sites along a transect inland from the coast. The sites (with their distance from the coast) were Berrimah Experiment Farm near Darwin (6 km), Coastal Plains Research Station (40 km), Upper Adelaide River Experiment Station (110 km), Douglas-Daly Experiment Station (130 km) and CSIRO's Research Station at Katherine (270 km). (All except the last are experiment stations of the Northern Territory Department of Primary Production.) In Queensland, material was exposed at CSIRO's Davies Laboratory at Townsville (10 km from coast), CSIRO's Lansdown Research Station near Woodstock (50 km), and the Queensland Department of Primary Industries' Swan's Lagoon Beef Cattle Field Research Station near Millaroo (70 km) and at Wrotham Park (170 km).

In June 1975, and in May 1976, 12 standard 'litter' samples were set out at each location. Each sample was spread evenly over bare soil, having a smooth, compact surface, within a retaining ring of plastic mesh 20 cm in diameter and 3 cm high. To discourage pests the soil was previously treated with dieldrin, and both a dieldrin-treated leaf and a commercial rodent bait were scattered around each ring. The area was protected from large animals by a large poultry netting cage.

In both 1975 and 1976 two samples were retrieved at approximately monthly intervals to provide information on cumulative changes over the dry season. In 1976 only, on each 'harvest' date, two fresh standard samples were set out; these were retrieved at the next harvest, thereby providing information on the change from the standard starting condition in each monthly period. These two types of samples will be referred to as 'cumulative' and 'monthly' samples.

Experiment 2

This experiment was described in detail in the first paper in this series (McCown *et al.* 1981). It was a study of sown swards of Caribbean stylo in 1978 at Katherine, Darwin, and Townsville from which litter was sampled at monthly intervals.

Meteorological Measurements

The full suite of instrumentation for a site was a rain-gauge; a Stevenson screen at 1·2 m containing a thermohygrograph and a minimum thermometer; a thermohygrograph set on the ground and shaded by a 2 cm thick Styrofoam cover measuring 40 cm by 40 cm; a terrestrial minimum thermometer mounted 5 cm above the soil surface; and a Duvdevani dew gauge mounted 5 cm above the soil surface. Although not all stations were completely instrumented, at all stations daily rain and dewfall were measured, and relative humidity was continuously recorded at one or both heights. These are the only three meteorological parameters used in this paper. It was not practical, except at Woodstock, to measure dewfall on the weekends, and long-term values at other stations were estimated from four values per week. Thermohygrographs were calibrated weekly; in experiment 1, terrestrial minimum thermometers and thermohygrographs were exposed, along with the dew gauge, under the cage; in experiment 2 they were placed in a 'hole' cut in the sward.

Calibrations of dew gauges were checked *en masse* before the study; each unit in use was stored indoors during the day and the top and bottom sides were exposed alternately; the units were generally discarded after 2 months use.

Quantification of Mouldiness of Litter

After harvest, each sample to be measured was mixed and a 1–2 g subsample taken. After removal of all stem and non-legume material, leaflets were sorted into one, two or three colour classes and the proportions calculated on an air-dry weight basis. The colour of each class was coded by using the Munsell Soil Colour Chart 10YR and transformed to a Discoloration Index (D.I.) as previously described (McCown *et al.* 1981). Mean D.I. for each sample was calculated by summing the products of the D.I. and the fraction of the total air-dry sample mass in each class. Since this was laborious, sample numbers were reduced by measuring colour on only one of a pair of samples when they were visually identical.

Results

The Effects of Rain

Rain usually resulted in increased mouldiness of dry-leaf litter, but the degree of this effect varied greatly. At one extreme, falls of 3·4, 2·8, and 2·2 mm at Woodstock and Townsville in 1976 (Table 1) and at Townsville, 1975 (Table 2) increased the D.I. of 'cumulative' samples by 4 units. At the other extreme, 15·2 mm at Darwin and 10·6 mm at Katherine in 1976 (Table 1) had no moulding effect. The relationship between D.I. and rain is shown in Fig. 1*a*. The regression was constrained to go through zero, since increases in D.I. did not occur without rain (see below). When all D.I. values were regressed with rainfall, only 23% of the variation in D.I. was accounted for.

Most samples from the Northern Territory received considerably more rain than those in Queensland for the same D.I. values (Fig. 1*a*). In the main, the first rain in the Northern Territory fell in spring when potential evaporation rates were very high. The exceptions, winter rainfall in 1978, are shaded and fall much closer to the Queensland observations, which were all falls in winter when evaporation rates were low. This suggests that further variation in mould growth would be accounted for by the inclusion of a parameter that reflects the variation in the rate of drying of rain-wetted litter.

The duration of wetness of normal, living leaves has been found to be closely correlated to the duration of high humidity (Smith 1962); we have used the hours of >95% R.H. near the ground to estimate the duration of wetness of litter following rain. The utility of this parameter can be seen by comparing the effects of a 12 mm rainfall at Katherine in July (1978) with those of a similar amount of rain in October

(1976) (Table 3). In July 1978, samples of litter were collected (in accordance with a predetermined monthly schedule) about 40 h after the single rainfall, by which time the D.I. of the leaf litter had increased by 2·1 units. The estimated period of litter wetness (>95% R.H. near ground) after rain was 18 h. In contrast, although the 10·6 mm of rain in October fell on 3 days over a 6-day period, no moulding resulted.

Table 1. Moulding (D.I.) of legume leaf, rain, duration of high humidity at 10 cm above ground, and dew in various periods in the 1976 dry season

Non-italicized numbers apply to the specific period; italicized numbers are cumulative over time

						Katherine, Northern Territory						
	13.v–8.vi		9.vi–7.vii		8.vii–11.viii		12.viii–1.ix		2.ix–3.x		4.x–1.xi	
Mean D.I.	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*
Rain (mm)	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*	10·6	*10·6*
Hours >95% R.H.	82	*82*	93	*175*	75	*250*	65	*315*	13	*328*	4	*332*
Dew-days	17	*17*	26	*43*	16	*59*	4	*63*	0	*63*		
Dew[A] (mm)	0·08	*1·4*	0·07	*3·2*	0·02	*3·5*	0·04	*3·7*	0	*3·7*		
						Adelaide River, Northern Territory						
	13.v–8.vi		9.vi–8.vii		9.vii–9.viii		10.viii–2.ix		3.ix–4.x		5.x–2.xi	
Mean D.I.	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*	2·3	*2·3*
Rain (mm)	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*	50·0	*50·0*
Hours >95% R.H.	54	*54*	52	*106*	78	*184*	78	*262*	79	*341*	99	*440*
Dew-days	22	*22*	23	*45*	20	*65*	12	*77*	23	*100*		
Dew (mm)	0·09	*2·0*	0·06	*3·4*	0·07	*4·8*	0·11	*6·1*	0·09	*8·2*		
						Darwin, Northern Territory						
	22.v–10.vi		11.vi–9.vii		10.vii–10.viii		11.viii–3.ix		4.ix–5.x		6.x–1.xi	
Mean D.I.	0	*0*	0	*0*	0	*0*	0	*0*	0	*0·3*	0·1	*0·5*
Rain (mm)	0	*0*	0	*0*	0	*0*	0	*0*	0	*0*	15·2	*15·2*
Hours >95% R.H.	75	*75*	81	*156*	140	*296*	113	*409*	146	*555*	48	*603*
Dew-days	13	*13*	14	*27*	17	*44*	24	*68*	19	*87*		
Dew (mm)	0·24	*3·1*	0·29	*7·2*	0·16	*10·0*	0·13	*13·1*	0·19	*16·7*		
						Millaroo, Queensland						
	27.v–16.vi		17.vi–5.vii		6.vii–2.viii		3.viii–30.viii		31.viii–29.ix		30.ix–27.x	
Mean D.I.	0	*0*	0	*1·4*	0	*1·4*	0	*1·3*	0	*1·4*	4·1	*6·0*
Rain (mm)	0	*0*	2·0	*2·0*	0	*2·0*	0	*2·0*	0	*2·0*	69·0	*71·0*
Hours >95% R.H.	168	*168*	168	*336*	176	*512*	178	*690*	189	*879*	168	*1047*
						Woodstock, Queensland						
	17.v–7.vi		8.vi–6.vii		7.vii–2.viii		3.viii–29.ix		30.ix–27.x			
Mean D.I.	0	*0*	2·3	*4·2*	1·7	*5·1*	1·3	*5·6*	3·9	*6·0*		
Rain (mm)	0·2	*0·2*	3·4	*3·6*	1·8	*5·4*	5·2	*10·6*	29·2	*39·8*		
Hours >95% R.H.	264	*264*	294	*558*	251	*809*	533	*1342*	270	*1612*		
Dew-days	15	*15*	20	*35*	19	*54*	49	*103*				
Dew (mm)	0·18	*2·7*	0·17	*6·1*	0·16	*9·1*	0·14	*16·0*				
						Townsville, Queensland						
	17.v–7.vi		8.vi–5.vii		6.vii–2.viii		3.viii–30.viii		31.viii–29.ix			
Mean D.I.	0	*0*	1·8	*4·1*	0	*4·5*	0	*4·2*	0	*4·1*		
Rain (mm)	0·8	*0·8*	2·8	*3·6*	0·2	*3·8*	0	*3·8*	0·1	*3·9*		
Hours >95% R.H.	182	*182*	239	*421*	127	*548*	206	*754*	220	*974*		

[A] First value in each period is average dewfall per dew-day.

In this case the estimated periods of wetness following rain events were 7, 3·5, and 1·5 h. It is emphasized that the role of high humidity is not as a source of water but rather as a constraint to evaporation from wet litter. Further contrasts in potential evaporation and related parameters can be seen in Table 3.

In Fig. 1*b*, cumulative changes in the D.I. have been plotted against cumulative hours >95% near-ground R.H. on days with >2 mm rain (an amount of rain sufficient to substantially wet the litter). The regression, when constrained to pass through zero, accounts for 91% of the variation in D.I. This regression has fewer observations than that on rainfall (Fig. 1*a*) because of some missing relative humidity data owing to recorder failure.

Table 2. Moulding (D.I.) of legume leaf, rain, duration of high humidity at 10 cm and dew in various periods in 1975 (experiment 1) and 1978 (experiment 2)

Non-italicized numbers apply to the specific period; italicized numbers are cumulative over time

Katherine, Northern Territory

1975:	14.vi–4.vii		5.vii–8.viii		9.viii–17.x	
Mean D.I.	0	*0*	—	*0*	—	*6·0*
Rain (mm)	0	*0*	0	*0*	23·5	*23·5*
Hours >95% R.H.	103	*103*	137	*240*	126	*366*
Dew-days	20	*20*	34	*54*	16	*70*
Dew[A] (mm)	0·10	*2·0*	0·07	*4·4*	0·05	*5·2*

Darwin, Northern Territory

1975:	14.vi–2.vii		3.vii–7.viii		8.viii–15.x	
Mean D.I.	0·3	*0·3*	—	*0·5*	—	*6·0*
Rain (mm)	0	*0*	0	*0*	53·5	*53·5*
Hours >95% R.H.	—	—	137	—	265	—
Dew-days	16	*16*	28	*44*	30	*74*
Dew (mm)	0·22	*3·5*	0·17	*8·3*	0·10	*11·3*

Townsville, Queensland

1975:	12.vi–2.vii		3.vii–30.vii		31.vii–11.viii		12.viii–10.ix	
Mean D.I.	0	*0*	—	*4·2*	—	*5·9*	—	*6·0*
Rain (mm)	0	*0*	2·2	*2·2*	12·8	*15·0*	50·5	*65·5*
Hours >95% R.H.	103	*103*	258	*361*	46	*407*	273	*680*

Katherine, Northern Territory

1978:	5.iv–13.v		14.v–14.vi		15.vi–11.vii		12.vii–28.viii	
Mean D.I.	—	*1·0*	—	*1·3*	—	*3·6*	—	*3·5*
Rain (mm)	0	*0*	2·2	*2·2*	12·2	*14·4*	0	*14·4*
Hours >95% R.H.	280	*280*	155	*435*	162	*597*	117	*714*

Darwin, Northern Territory

1978:	8.iv–18.v		19.v–19.vi		20.vi–12.vii	
Mean D.I.	—	*2·9*	—	*4·9*	—	*6·0*
Rain (mm)	4·2	*4·2*	16·4	*20·6*	12·0	*32·6*
Hours >95% R.H.	—	—	—	—	—	—

[A] First value in each period is average dewfall per dew-day.

The Effects of Dew

The highest D.I. value for any sample in experiment 1 that was not wetted by rain was 0·5 (Darwin, Table 2). Thus moulding in the absence of rain was very slight, in spite of some heavy dewfall at some sites. In 1976 Darwin and Woodstock received a total of 16 mm of dew from May to October. At Darwin, up to 9 July the average depth of dew on 27 days was over 0·26 mm/day. Similar heavy falls occurred early in 1975 at Darwin.

The amount of dewfall received varied along the Northern Territory transect inland from the coast. In 1976, Adelaide River received about half that of Darwin, and Katherine about half that of Adelaide River (Table 1). Dew occurred more frequently inland (Katherine) than on the coast (Darwin) during the early periods, although falls were very much lighter. This was reversed in the later periods (Tables 1 and 2). A moulding effect was detectable as a change in sample D.I. only at Darwin, and this was slight.

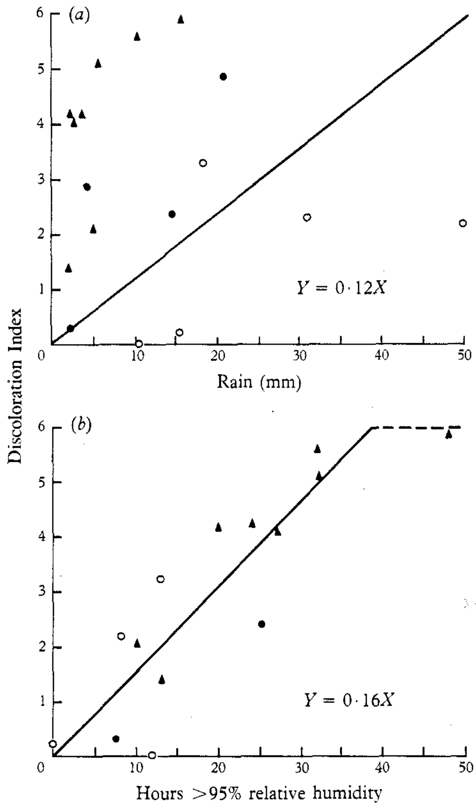

Fig. 1. (*a*) The relationship between mouldiness (Discoloration Index) of leaf and rainfall. (*b*) The relationship between mouldiness and the duration of >95% relative humidity at 10 cm following >2 mm rain. (▲ Qld stations; ● N.T. stations in winter; ○ N.T. stations in spring).

The records of dewfall in Queensland were too incomplete to be reported, with the exception of Woodstock in 1976 and Wrotham Park in 1975 and 1976. However, the data that were collected at Millaroo and Townsville indicate that occurrences and amounts of dew were similar to those at Woodstock. In any case, detection of the long-term effects of dew on moulding of litter is not often possible in this coastal–subcoastal region owing to rain (Tables 1 and 2). At the most inland station (Wrotham Park), cumulative dewfall in 1976 (13 May–4 October) was 9·2 mm on 90 dew-days, and in 1975 (14 June–16 October) 6·9 mm on 93 dew-days; in neither year did the D.I. of exposed samples increase as a result of dewfall.

The Effects of High Humidity

The number of hours with >95% R.H. varied greatly between stations and between years (Tables 1 and 2), but in general there was no detectable moulding, even under the most humid regimens. For example, in 1976 (experiment 1) at

Woodstock, there was a total of 264 h in the 21 days of the May–June period, which was more than three times that at Katherine in a similar period; however, at neither location did the D.I. exceed zero. The only case where detectable moulding occurred was at Katherine in 1978 during the April–May period, when 280 h of >95% R.H. resulted in a D.I. of 1·0.

Table 3. A comparison of the duration of wetness (hours >95% relative humidity near ground) following rain between a period of low evaporation potential (Epan) and one of high evaporation potential at Katherine, N.T.

Date	Rain (mm)	Duration of >95% R.H. (h)	Epan (mm)	Wind run (km)	Total radiation (mW h cm^{-2})	Max. temp. (°C)
July 1978						
9	0·2	0	5·2	195	97	29
10	12·2	18·0	2·8	111	341	27
11 (Harvest)		5·0	2·4	45	457	26
October 1976						
25	1·9	7·0	8·1	163	753	39
26		0	10·0	156	681	40
27		0	10·0	150	681	41
28		0	10·6,	152	629	40
29	7·1	3·5	8·7	211	408	35
30	1·6	1·5	3·4	100	754	39
31		1·0	10·8	245	785	41
1 (Harvest)		0	12·8	301	717	39

Exposure to high humidity or dew appears to have predisposed samples to faster moulding when subsequently wetted by rain. The test for this is to compare the effects of rain on 'cumulative' and 'monthly' samples after a period of exposure of the 'cumulative' sample insufficient to cause an increase in D.I. This 'priming' effect was pronounced at Millaroo, Woodstock, and Townsville in June 1976 (Table 1), but at the Northern Territory location the only evidence of any such effect was small, at Darwin in 1976. In general, humidity regimens in the Northern Territory were much lower than in Queensland (Tables 1 and 2).

Discussion

'Standing hay', i.e. a sward of naturally desiccated unmown herbage saved for grazing in the dry season, has obvious generic similarity to the fodder produced by mowing, drying, and storing under cover. The extent to which each type of hay can extend the benefits of the most productive season into periods in which stock suffer nutritional deficits depends largely on the avoidance of moulding. The economic importance of safe storage of conventional hay has stimulated considerable research on causes of hay moulding; the resultant cause-and-effect principles provide a basis for understanding the control of moulding of 'standing' hay.

Mould growth on hay is limited by the water potential at spore sites on the surfaces of hay components. Water potential at these sites can be maintained or increased by diffusion of water (*a*) from within the component itself or (*b*) from the air. It has been clearly established that the speed and extent of moulding is determined more by the relative humidity of the air in contact with the hay than by the bulk water percentage of the hay itself (Wright 1941; Snow *et al.* 1944). The water content of the hay and the air are, however, interdependent, and water is transferred from one to the other along potential gradients. This has two important implications. Firstly, well-cured hay will take up water and will mould if exposed to wetter air. However, the rate of diffusion is slow; Wright (1941) found that the equilibrium water content of a thin layer of tissue in 100% relative humidity was approached only after 6–8 days; fungal growth was observed after 3 days. The rate of movement of surface moisture to deeper layers is exceedingly slow, and this retention at the surface tends to accelerate surface mould growth (Dexter 1955). Secondly, hay with a high moisture content will mould very quickly if surrounded by wet air, but may not mould at all if it is well ventilated by air with a relative humidity lower than *c.* 75% (Snow *et al.* 1944; Dexter 1955).

Although the same principles apply to 'standing hay', the water environment of the fungi is controlled by quite different factors. In contrast to conventional hay under cover, the results reported in this paper show that the absorption of water from moist air by plant surfaces is not an important mechanism in the promotion of mould growth on 'standing hay'. There are two major reasons why this should be expected. Firstly, tissue which has been dried to a very low water content during the day cannot take up much water overnight. This is due to the slow diffusion rates even in moist air (Wright 1941) and to the relatively short duration of exposure to high humidity. Near-ground humidities higher than 95% rarely occurred for longer than 14 h on a rainless day, even at the most humid sites (Townsville, Woodstock and Millaroo). Secondly, the nocturnal increase in the relative humidity of the air in and just above the litter tends to be less than that of air further from the soil surface (Baier 1966). Heat flux from the soil at night is retarded by the litter 'blanket', thereby prolonging the decline in temperature and thus maintaining lower relative humidity near the ground. Hence it appears that in an environment with such strong checks on prolonged high humidity near the ground, appreciable moulding of forage can occur only when precipitation supplies the water.

One source of water to promote moulding is dew. Although substantial amounts of water were precipitated as dew at some sites, e.g. Darwin and Woodstock, the effect on moulding of the bulk litter sample was small even after 5 months of exposure. However, at Darwin, where dew effects were not masked by the effects of rain, there was dense mould growth on the immediate surface layer of the sample. (In grazing studies on legume pastures, a very mouldy thin surface did not deter cattle from eating the mass of high quality leaf litter underneath (M. J. Playne and R. L. McCown, unpubl. data).) Early in 1976 the first signs of moulding at Darwin, and usually the only moulding at other locations with less dewfall, were the blackening of leaf portions projecting above the sample surface, which indicates the higher frequency with which the most exposed portion of the material dropped below the dewpoint. To conclude that dew is of little importance in promoting moulding from studies which used simulated litter exposed without any upper storey of standing plant parts is unlikely to underrate the dew factor. The work of Baier (1966) indicates that even less dew would be expected near the ground in a natural sward. Mäde (1956, cited by Baier 1966) recorded that the maximum dewfall near the top of the canopy of small grain crops was more than 25 times that near the ground. (Although nocturnal wetting and moulding is much greater on the standing portions of our legume swards, this material was not included in our study because of the inherently low nutritive value of Caribbean stylo stem (Gardener 1980).)

The results indicate that only rain can supply sufficient moisture to the litter portion of legume standing hay to promote significant moulding, and that if evaporation rates are low, as little as 2–3 mm can cause serious damage. By assuming that its value as a fodder approaches zero at a D.I. of about 5 (McCown *et al.* (1981) found that cattle refused to eat litter with a D.I. of 6), the total loss of legume-litter value requires about 35 h of wet conditions. In no case in these studies was this condition reached in one continuous period following one rainfall event; instead it required 2 or more rain-days.

The 'priming' effect of high humidity, dew and/or small rainfalls is perhaps because such a moisture regimen permits spore germination and some mycelium development. Although this growth is inconspicuous in itself, it apparently amounts to a major step along the growth–time function toward the 'grand period' of growth. This rapid growth phase may then be reached earlier in an ensuing rain–wet period than would be otherwise possible.

Although the amount of rain above that necessary to wet the litter seems unimportant in controlling moulding, it may affect the nutritive value of litter by leaching. Where rapid drying prevented moulding, this could have been significant. These effects on chemical composition will be treated in another paper.

The improved understanding of what weather conditions cause moulding losses provides a means of assessing the geographic variation in risks of such losses by using existing meteorological records. The model from Part I (McCown *et al.* 1981) permits the prediction of leaf fall and leaf litter accumulation. The results of the studies reported in this paper form the basis of a model of mould damage of this forage in relation to weather conditions following leaf shedding. Variation in the risk of moulding losses across the beef-producing region of tropical Australia is the subject of the next paper in this series.

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