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STUDIES IN THE ENVIRONMENT OF QUEENSLAND. 1, THE CLIMATOLOGY OF SEMI-ARID PASTORAL AREAS.

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SUMMARY.

The literature dealing with climatic classification is reviewed, and the P/E ratio used as a method of measuring effective rainfall.

The seasonal incidence of effective rainfall is calculated for bi-monthly periods, and zonation is undertaken on the basis of its reliability.

Summer and winter P/E differences, mean minimum winter and mean maximum summer temperatures are considered and the broad influence of climatic factors on the growth and distribution of plants and on sheep husbandry is discussed.

INTRODUCTION.

The study of climate is of paramount importance in a primary producing country where the production of wool, meat and milk depends largely upon natural vegetation. Different climatic zones produce vegetation specific to themselves and thus the type of primary production best suited to any given region depends largely upon its climate.

In a pastoral zone methods of animal husbandry often make the difference between success and failure. This is especially true in the raising of Merino sheep. Wool is expensive to produce and it is important that the utmost efficiency be attained in its production. To do this it is essential that the influence of environment be thoroughly understood. It is essential, also, to know how far results obtained from different methods of husbandry in one district can be applied to others, and to determine the limits of economic wool production and economic sheep-breeding.

The results of a study which has been made of the climatic data from the semi-arid region of Queensland are presented in this paper. It is obvious that considerable differences exist in the climate of various parts of the main sheep grazing areas of the State, and it is thought that these differences may be correlated with natural vegetation, which in turn governs the growth and reproduction of sheep as well as wool production.

LITERATURE.

Various criteria have been used for the classification of climate and the different methods have been reviewed by Moreau (1938) and Prescott (1934), who indicate the limitations and applications of the classifications offered by a number of writers, including those of Köppen, Thornthwaite, de Martonne, Emberger, Meyer, Lang, Prescott, Davidson and Trumble.

Köppen (see Moreau, 1938, and Lawrence, 1937) divided the world into climatic zones using temperature, rainfall and rainfall distribution. Thornthwaite (1931, 1933; see also Moreau, 1938, and Prescott, 1934) obtained his "precipitation efficiency index" as a complicated function of rainfall and temperature, but took no account of relative humidity. Both of these methods are useful over large areas, but are not suitable for application to a particular region, such as the pastoral areas of Queensland.

Andrews and Maze (1933) used a modification of de Martonne's "Index of Aridity" ($\frac{P}{T + 10}$, where P = precipitation in cms., T = °C.) in Australia with some success. Their method was to classify climates on the basis of the number of dry months in the year, the criterion of a dry month being an index of less than 1. Again, humidity was not taken into account. It seems that, where wet and dry bulb readings are available, the humidity should be considered, its controlling effect on evaporation being obvious.

Davidson (1933, 1935) and Prescott (1934, 1936) investigated the Meyer Ratio $\frac{P}{S.D.}$ (where P = precipitation; S.D. = saturation deficit, which is the difference between the saturation vapour pressure of water at a given temperature and the partial pressure of water vapour actually present in the environment at that temperature). Davidson (1934, 1935) applied the supposition that evaporation from a free water surface is proportional to saturation deficit, provided all other factors are constant. Actually wind velocity, atmospheric pressure, insolation, turbulence, exposure, and nature of land surface have an effect on evaporation. Prescott's investigation of 144 monthly values at a selected range of 12 Australian stations (1938) showed a correlation coefficient of ·972 between evaporation and saturation deficit. Davidson (1933) showed that for South Australia mean monthly values of S.D. could be expressed in terms of evaporation by referring to data for a free water surface at Adelaide and he formulated the equation $\frac{P}{E} = m \frac{P}{S.D.}$ (where m is a constant). Prescott (1938) worked with this conversion factor, using the formula $E = 21.2$ S.D. for a month of 30 days. The same numerical relationship was used by Lawrence (1941) in an analysis of the climate of tropical Australia.

Prescott (1934; see also Moreau, 1938) noted the weakness of using maximum and minimum temperatures for the calculation of saturation deficit and stated that the minimum is less important than the dew point. In semi-arid regions this is true to some extent but it is not as important as in more humid areas, since on a very large number of days during the year minimum temperatures do not fall below the dew point. This applies particularly to Queensland, where the air masses in winter are mostly of the dry continental type.

Prescott (1942, 1943) also pointed out the existence of a difference in phase between temperature and evaporation. This difference shows a maximum of 21 days at the ocean coast and falls off rapidly to values of the order of seven days within 150 miles of the coast. The only data available are on a monthly basis so it was not found practicable by the authors to apply any correction for phase lag, and it was assumed that monthly evaporation is a function of the temperature and humidity recorded for the same month.

Prescott (1938) concluded that, to find some expression for the climatic conditions of a given environment, temperature, rainfall and humidity must be linked with soil moisture conditions, and the P/E Transeau ratio appeared to be a practical measure of effective soil moisture, E being calculated from temperature and humidity. Trumble (1939) considered a value of $P/E = \cdot 3$ (computed from total rainfall and evaporation for any one month) as being effective for producing plant growth in South Australia. The difference in values required for South Australia and tropical Australia were noted by Lawrence (1941). In her study of climate in the latter part of the continent she used $P/E = \cdot 25$ as the minimum ratio limiting a month of effective rainfall.

Szymkiewiez (1925) suggested the substitution of $\text{S.D.} \times \frac{273 + T}{273}$ for S.D. in Prescott's equation, given above, thus taking into consideration the greater diffusivity of water vapour at higher temperatures. It was considered by the present authors that the accuracy of the data did not warrant the application of such a detailed method for their studies.

Apart from its effect on evaporation, temperature itself has a profound influence on plant growth and on the growth and reproduction of animals. No experimental work on the temperature requirements of the plants constituting the vegetative cover of the sheep-raising areas of Queensland is known. Klages (1942), discussing temperature efficiencies in relation to crop distribution, quotes a number of authorities giving a general "zero of vital temperature point" as 40°F. or 4·4°C. Forster (1941) gives 42°F. as the lowest limit for flax growth.

Lee and his co-workers (1947) found adult sheep to be remarkably tolerant of high temperatures, but plane of nutrition had a marked effect on their reactions. Gunn and his co-workers (1942) studied the effects of high temperatures on the morphology, motility and longevity of spermatozoa produced by rams enjoying normal sexual health. They found that animals subjected to daily maximum temperatures of over 95°F., under conditions of low humidity, for a period of 28 days became comparatively infertile. Recovery, as judged by the seminal picture, took place in about 2½ months if the rams were adequately fed and if the weather was cool.

Table

Values for various factors

Station.	Late Spring. October–November.					Early Summer. December–January.					Late Summer. February–March.				
	P.	T.	S.D.	E.	P/E.	P.	T.	S.D.	E.	P/E.	P.	T.	S.D.	E.	P/E.
Burketown	1·81	82·9	·63	20·16	·09	12·51	85·5	·48	15·36	·81	11·38	83·7	·40	12·80	·89
Cloncurry	1·68	83·8	·79	25·28	·07	7·03	87·6	·76	24·48	·29	6·65	84·9	·63	20·32	·33
Croydon	2·26	86·9	·74	23·68	·10	13·14	86·6	·51	16·32	·81	10·80	84·5	·42	13·60	·79
Donor's Hill ..	2·24	85·0	·76	24·32	·09	11·55	86·8	·61	19·52	·59	9·32	84·1	·47	15·20	·61
Normanton	2·22	85·7	·62	19·84	·11	16·77	86·3	·42	13·60	1·23	15·93	84·6	·33	10·56	1·51
Georgetown	2·48	83·1	·65	20·96	·12	13·90	83·8	·48	15·52	·90	12·45	81·6	·40	12·96	·96
Hughenden	2·07	80·8	·67	21·44	·10	7·12	84·6	·60	19·20	·37	6·04	81·5	·45	14·56	·41
Mount Surprise ..	2·57	79·2	·50	16·00	·16	12·60	81·2	·41	13·28	·95	11·61	78·2	·31	9·92	1·17
Richmond	1·80	82·4	·73	23·52	·08	6·81	86·1	·68	21·76	·31	6·42	83·1	·53	16·96	·38
Atherton	3·39	70·8	·28	9·12	·37	19·13	74·4	·23	7·36	2·60	19·41	72·4	·14	4·64	4·18
Cairns	5·98	77·9	·32	10·24	·58	25·23	81·7	·31	9·92	2·54	33·81	80·7	·24	7·84	4·31
Cooktown	3·53	80·1	·32	10·24	·34	21·00	82·1	·27	8·64	2·43	29·02	81·1	·22	7·04	4·12
Herberton	3·57	70·4	·27	8·80	·41	15·31	73·5	·23	7·52	2·04	15·72	72·1	·15	4·80	3·28
Port Douglas ..	5·92	77·2	·29	9·28	·64	24·28	80·4	·28	8·96	2·71	32·35	79·6	·24	7·68	4·21
Cardwell	6·19	75·2	·26	8·32	·74	25·07	79·5	·25	8·16	3·07	32·87	78·9	·19	6·08	5·41
Innisfail	9·59	75·2	·21	6·72	1·43	31·74	79·4	·22	7·04	4·51	49·38	78·6	·14	4·64	10·64
Townsville	3·20	78·2	·36	11·68	·28	16·32	81·3	·33	10·56	1·55	18·38	80·7	·30	9·76	1·88
Ayr	2·70	76·6	·36	11·68	·23	15·16	80·8	·34	11·04	1·37	15·60	79·7	·28	9·12	1·71
Bowen	2·27	77·4	·34	11·04	·21	14·28	81·2	·32	10·40	1·37	14·52	80·5	·27	8·80	1·65
Mackay	4·82	75·0	·29	9·28	·52	20·99	79·5	·29	9·28	2·26	23·85	78·3	·21	6·88	3·47
St. Lawrence ..	4·20	74·8	·33	10·72	·39	13·94	79·6	·33	10·56	1·32	12·96	78·7	·27	8·64	1·50
Charters Towers ..	2·17	78·5	·42	13·60	·16	8·67	81·9	·41	13·28	·65	8·20	79·5	·33	10·72	·76
Blackall	2·87	78·5	·59	19·04	·15	5·36	84·9	·67	21·60	·25	5·91	82·3	·53	16·96	·35
Clermont	3·39	77·3	·46	14·72	·23	8·63	81·9	·45	14·56	·59	7·35	78·7	·34	11·04	·67
Emerald	3·64	77·1	·44	14·08	·26	7·42	82·1	·44	14·24	·52	6·25	79·8	·36	11·52	·54
Springsure	4·07	75·7	·43	13·92	·29	7·41	8·07	·44	14·08	·53	6·64	78·5	·38	12·16	·55
Tambo	3·12	75·2	·50	16·16	·19	5·49	81·4	·57	18·24	·30	5·46	79·0	·44	14·24	·38
Barcaldine	2·53	78·2	·58	18·56	·14	5·38	84·0	·61	19·68	·27	5·52	81·4	·50	16·00	·34
Isisford	2·35	79·2	·60	19·36	·12	4·33	85·4	·65	20·80	·21	5·50	82·8	·53	17·12	·32
Longreach	2·09	79·7	·61	19·68	·11	4·09	85·5	·67	21·44	·19	5·87	82·8	·52	16·64	·35
Camooweal	1·74	83·1	·77	24·80	·07	5·73	86·9	·74	23·68	·24	5·48	84·1	·58	18·72	·29
Kynuna	1·78	81·7	·67	21·60	·08	5·49	86·3	·68	21·76	·25	5·56	83·1	·53	17·12	·32
Urandangie	1·23	81·3	·84	26·88	·05	3·53	87·5	·91	29·28	·12	3·97	84·4	·73	23·52	·17
West Leichhardt ..	2·33	81·4	·73	23·52	·10	6·75	85·6	·70	22·40	·30	5·69	82·0	·57	18·40	·31
Winton	1·92	81·5	·71	22·88	·08	4·96	86·9	·75	24·00	·21	5·38	84·0	·58	18·72	·29
Boulia	1·40	81·0	·78	25·12	·06	2·94	87·7	·88	28·16	·10	3·50	85·4	·74	23·68	·15
Windorah	1·53	78·7	·70	22·56	·07	2·72	86·3	·86	27·52	·10	3·26	83·9	·74	23·68	·14
Bundaberg	4·81	72·3	·29	9·44	·51	13·63	77·4	·32	10·24	1·33	11·71	76·5	·26	8·32	1·41
Childers	5·50	72·7	·28	9·12	·60	12·98	77·1	·28	9·12	1·42	11·34	76·0	·23	7·36	1·54
Gayndah	5·37	72·9	·35	11·20	·48	8·76	78·1	·36	11·52	·76	7·20	76·3	·31	9·92	·73
Gladstone	4·72	73·8	·31	9·92	·48	12·37	78·3	·30	9·76	1·27	12·06	77·6	·27	8·64	1·40
Mount Morgan ..	4·32	74·4	·31	9·92	·44	9·97	78·3	·30	9·76	1·02	8·63	76·6	·26	8·48	1·02
Rockhampton ..	4·22	76·4	·37	11·84	·36	12·39	80·6	·36	11·52	1·08	12·11	79·2	·29	9·44	1·28
Westwood	4·01	73·8	·32	10·24	·39	8·80	78·5	·32	10·40	·85	7·50	76·6	·28	9·12	·82
Gympie	6·02	72·0	·28	8·96	·67	11·97	77·1	·27	8·80	1·36	12·98	75·5	·21	6·88	1·89
Ipswich	5·33	72·7	·35	11·36	·47	8·29	78·1	·37	12·00	·69	8·48	76·1	·31	10·08	·84
Maryborough ..	5·97	72·7	·31	9·92	·60	12·10	77·5	·32	10·40	1·17	12·67	76·3	·24	7·84	1·62

P = mean rainfall in inches.

$$T = \frac{\text{mean maximum + mean minimum temperature °F.}}{2}$$

S.D. = saturation deficit in inches.

1.

for 65 Queensland stations.

AUTUMN. April–May.					WINTER. June–July.					EARLY SPRING. August–September.					P/E. Diff.
P.	T.	S.D.	E.	P/E.	P.	T.	S.D.	E.	P/E.	P.	T.	S.D.	E.	P/E.	
1·22	77·1	·51	16·48	·07	·32	69·0	·41	13·12	·02	·11	73·4	·52	16·80	·01	+ ·87
1·17	75·0	·54	17·44	·07	·96	64·9	·35	11·36	·08	·42	71·4	·54	17·28	·02	+ ·25
1·34	79·2	·51	16·48	·08	·49	71·4	·40	12·80	·04	·32	77·3	·56	18·08	·02	+ ·75
1·40	76·1	·53	16·96	·08	·70	67·7	·40	12·80	·05	·30	73·9	·56	18·08	·02	+ ·56
1·93	79·6	·47	15·04	·13	·56	72·1	·35	11·36	·05	·16	77·1	·49	15·68	·01	+ 1·46
1·56	75·3	·43	13·76	·11	·74	68·2	·34	11·04	·07	·54	73·2	·47	15·04	·04	+ ·90
1·65	71·7	·37	12·00	·14	1·38	62·6	·24	7·68	·18	·71	69·1	·40	12·96	·05	+ ·23
1·96	71·3	·30	9·76	·20	·99	64·3	·22	7·20	·14	·38	69·1	·34	11·04	·03	+ 1·03
1·41	73·2	·44	14·08	·10	1·13	63·7	·29	9·44	·12	·37	70·3	·48	15·36	·02	+ ·26
6·50	66·1	·12	3·84	1·69	2·74	61·0	·10	3·20	·86	1·62	63·3	·17	5·44	·30	+ 3·32
15·80	75·5	·19	6·24	2·53	4·43	70·4	·18	5·92	·75	3·40	72·0	·24	7·68	·44	+ 3·56
11·58	77·5	·22	7·04	1·64	2·95	73·1	·19	6·08	·49	1·76	74·9	·24	7·84	·22	+ 3·64
5·51	66·1	·12	4·00	1·38	2·02	60·4	·09	3·04	·66	1·19	63·0	·18	5·76	·21	+ 2·61
11·96	75·1	·22	7·04	1·70	3·03	69·8	·19	6·24	·49	2·23	71·3	·24	7·68	·29	+ 3·72
12·37	73·0	·16	5·12	2·42	3·39	66·1	·13	4·32	·78	2·78	68·1	·16	5·28	·53	+ 3·32
32·37	73·2	·11	3·68	8·79	11·98	67·2	·10	3·20	3·74	8·43	68·9	·13	4·16	2·02	+ 6·90
4·60	75·3	·32	10·40	·44	1·98	68·7	·26	8·48	·23	1·24	71·5	·30	9·76	·13	+ 1·65
3·56	73·7	·27	8·80	·40	2·15	66·2	·21	6·72	·32	1·85	68·9	·26	8·32	·22	+ 1·39
3·95	74·0	·24	7·68	·51	2·57	66·7	·20	6·56	·39	1·43	69·7	·25	8·00	·18	+ 1·26
9·88	70·9	·17	5·60	1·76	4·40	63·1	·13	4·32	1·02	2·68	66·1	·19	6·08	·44	+ 2·45
4·51	71·2	·23	7·52	·60	3·88	63·4	·16	5·28	·73	2·04	66·5	·22	7·20	·28	+ ·77
2·26	72·2	·30	9·60	·24	1·96	64·5	·21	6·88	·28	1·31	69·2	·29	9·28	·14	+ ·48
2·71	68·5	·33	10·72	·25	2·32	57·9	·18	5·92	·39	1·40	64·4	·23	10·56	·13	— ·14
2·90	68·1	·26	8·48	·34	2·74	58·7	·16	5·12	·54	1·64	64·5	·27	8·64	·19	+ ·13
2·43	68·9	·27	8·64	·28	2·80	59·4	·17	5·44	·51	1·91	64·7	·27	8·64	·22	+ ·03
2·76	67·5	·30	9·60	·29	2·94	57·7	·19	6·24	·47	2·19	63·5	·29	9·28	·24	+ ·08
2·72	65·7	·29	9·28	·29	2·45	55·7	·15	4·96	·49	1·60	61·8	·29	9·44	·17	— ·11
2·53	69·4	·34	10·88	·23	2·15	59·4	·20	6·56	·33	1·23	65·2	·35	11·20	·11	+ ·01
2·29	69·2	·35	11·20	·20	1·96	58·9	·21	6·88	·28	1·15	65·3	·35	11·20	·10	+ ·04
1·78	70·0	·36	11·68	·15	1·68	59·6	·21	6·72	·25	·82	65·9	·36	11·68	·07	+ ·10
·79	73·4	·51	16·48	·05	·92	63·3	·33	10·72	·09	·33	70·5	·51	16·48	·02	+ ·20
1·22	72·4	·42	13·44	·09	1·25	61·9	·24	7·68	·16	·44	68·7	·41	13·12	·03	+ ·16
·86	71·2	·53	16·96	·05	·81	60·7	·32	10·40	·08	·35	67·7	·51	16·32	·02	+ ·09
·98	72·4	·47	15·04	·07	·77	62·6	·32	10·40	·08	·41	68·3	·46	14·72	·03	+ ·24
1·37	72·2	·43	13·76	·10	1·46	61·6	·26	8·32	·18	·61	68·2	·43	13·92	·04	+ ·11
·97	70·9	·47	15·04	·06	·85	60·0	·26	8·32	·10	·52	67·1	·44	14·24	·04	+ ·05
1·55	68·3	·40	12·80	·12	1·31	57·1	·21	6·72	·19	·84	64·2	·39	12·64	·07	— ·05
5·82	68·9	·20	6·56	·89	4·69	61·1	·15	4·80	·98	2·84	64·1	·20	6·40	·44	+ ·43
4·89	68·6	·19	6·24	·78	4·15	61·1	·16	5·12	·81	2·98	64·3	·21	6·72	·62	+ ·73
2·98	66·3	·23	7·36	·40	3·28	57·5	·15	4·96	·66	2·70	61·7	·23	7·36	·37	+ ·07
4·30	70·6	·25	8·00	·54	4·49	63·0	·17	5·44	·83	2·21	65·9	·23	7·36	·30	+ ·57
3·39	68·1	·21	6·88	·49	3·80	59·7	·14	4·48	·85	2·01	64·6	·21	6·88	·29	+ ·17
4·12	71·6	·24	7·84	·53	4·34	62·9	·17	5·44	·80	2·10	67·3	·24	7·68	·27	+ ·48
3·46	66·9	·22	7·20	·48	3·60	58·8	·14	4·64	·78	2·13	63·3	·21	6·88	·31	+ ·04
6·21	66·7	·15	4·80	1·29	4·75	58·1	·11	3·68	1·29	3·80	61·8	·16	5·12	·74	+ ·60
4·31	63·5	·19	6·08	·71	3·68	57·5	·14	4·64	·79	3·13	61·7	·22	7·04	·44	+ ·05
6·82	68·2	·19	6·08	1·12	4·92	60·4	·13	4·32	1·14	3·57	63·4	·20	6·56	·54	+ ·48

E = evaporation (calculated from saturation deficit) in inches.

P/E = ratio of precipitation to evaporation.

P/E Diff. = P/E for January-February-March—P/E for June-July.

Table 1

Station.	Late Spring. October–November.					Early Summer. December–January.					Late Summer. February–March.				
	P.	T.	S.D.	E.	P/E.	P.	T.	S.D.	E.	P/E.	P.	T.	S.D.	E.	P/E.
Dalby	4·99	71·0	·37	11·84	·42	6·86	76·6	·39	12·64	·54	5·53	74·5	·34	10·88	·51
Goondiwindi	3·95	72·3	·39	12·48	·31	5·90	79·5	·48	15·36	·38	4·90	77·2	·39	12·48	·39
Pittsworth	4·97	68·3	·31	10·08	·49	7·57	73·5	·32	10·24	·74	5·48	71·9	·29	9·28	·59
Stanthorpe	5·22	63·0	·24	7·84	·67	7·22	69·4	·28	8·96	·81	5·68	67·7	·22	7·20	·79
Wallangarra	5·60	62·1	·22	7·04	·80	7·81	68·0	·28	9·12	·86	5·57	66·8	·24	7·84	·71
Warwick	4·95	67·6	·28	9·12	·54	7·14	73·7	·33	10·56	·68	5·64	71·8	·27	8·80	·64
Miles	4·57	72·6	·38	12·32	·37	6·99	78·7	·42	13·60	·51	5·42	76·6	·34	10·88	·50
Mitchell	3·66	72·0	·46	14·72	·25	5·79	79·2	·53	16·96	·34	5·56	76·5	·42	13·44	·41
Roma	3·85	73·7	·45	14·40	·27	5·69	80·2	·51	16·32	·35	5·47	78·0	·42	13·60	·40
St. George	2·94	73·8	·44	14·08	·21	4·68	81·8	·56	17·92	·26	4·39	78·9	·45	14·40	·30
Surat	3·53	73·2	·38	12·32	·29	5·55	80·5	·47	15·20	·37	5·30	78·1	·39	12·48	·42
Yuleba	4·35	72·8	·40	12·80	·34	5·91	78·6	·43	13·76	·43	5·74	76·7	·37	11·84	·48
Bollon	2·65	74·2	·44	14·24	·19	4·50	82·1	·55	17·60	·26	3·59	79·7	·45	14·40	·25
Charleville	2·87	75·5	·54	17·28	·17	4·82	82·7	·65	20·64	·23	4·80	80·3	·53	16·96	·28
Cunnamulla	1·87	74·7	·55	17·76	·11	3·03	82·7	·67	21·60	·14	3·30	80·1	·55	17·60	·19
Adavale	2·13	77·0	·63	20·16	·11	3·95	84·6	·76	24·48	·16	3·82	82·5	·65	20·96	·18
Thargomindah	1·65	76·1	·64	20·64	·08	2·74	84·5	·83	26·56	·10	2·14	82·3	·71	22·72	·09

P = mean rainfall in inches.

$$T = \frac{\text{mean maximum} + \text{mean minimum temperature °F.}}{2}$$

S.D. = saturation deficit in inches.

—continued.

Autumn. April–May.					Winter. June–July.					Early Spring. August–September.					P/E. Diff.
P.	T.	S.D.	E.	P/E.	P.	T.	S.D.	E.	P/E.	P.	T.	S.D.	E.	P/E.	
2·65	63·1	·21	6·88	·39	3·33	53·6	·12	3·84	·87	2·78	58·7	·22	7·04	·39	– ·36
3·04	63·7	·21	6·88	·44	3·43	53·5	·11	3·52	·97	2·68	59·0	·20	6·56	·41	– ·58
2·98	61·2	·20	6·56	·45	3·52	52·1	·12	3·84	·92	2·76	57·0	·19	6·08	·45	– ·33
3·42	56·0	·13	4·16	·82	3·92	46·7	·08	2·56	1·53	3·97	51·0	·14	4·48	·88	– ·74
2·96	56·2	·15	4·96	·60	4·22	47·4	·09	3·04	1·39	3·40	51·0	·16	5·12	·66	– ·68
3·06	60·7	·16	5·28	·58	3·48	51·3	·09	2·88	1·21	3·21	55·5	·16	5·12	·63	– ·57
2·89	63·6	·21	6·88	·42	3·26	53·4	·12	4·00	·82	2·42	59·2	·22	7·20	·34	– ·31
2·56	62·3	·22	7·20	·36	2·98	52·4	·11	3·68	·81	2·13	58·1	·24	7·68	·28	– ·40
2·68	64·1	·24	7·84	·34	2·94	53·9	·12	3·84	·77	2·26	60·1	·23	7·52	·30	– ·36
2·66	64·6	·28	8·32	·29	2·70	53·8	·12	4·00	·68	1·97	59·8	·23	7·36	·27	– ·37
2·50	64·5	·23	7·52	·33	3·38	53·9	·11	3·68	·97	2·26	59·9	·21	6·88	·33	– ·50
2·73	62·9	·22	7·20	·38	3·22	52·9	·12	4·00	·81	2·20	58·8	·22	7·20	·31	– ·33
2·24	64·4	·23	7·52	·30	2·42	53·4	·11	3·68	·66	1·91	59·5	·22	7·04	·27	– ·40
2·52	65·6	·30	9·60	·26	2·51	54·7	·14	4·64	·54	1·60	61·0	·29	9·44	·17	– ·26
2·12	65·0	·29	9·44	·22	2·01	54·3	·14	4·64	·43	1·48	60·8	·29	9·28	·16	– ·25
2·01	66·8	·34	10·88	·18	2·17	55·6	·18	5·76	·38	1·13	62·3	·33	10·72	·11	– ·20
1·58	66·0	·35	11·20	·14	1·25	54·7	·17	5·60	·22	·99	61·5	·34	10·88	·09	– ·13

E = evaporation (calculated from saturation deficit) in inches.

P/E = ratio of precipitation to evaporation.

P/E Diff. = P/E for January–February–March—P/E for June–July.

DATA AVAILABLE.

Limited data were available and these consisted of:

(i.) Monthly rainfall totals for periods of 50 years and over for 65 Queensland stations. The mean was calculated and is set down with other data used in Table 1.

(ii.) The mean monthly maximum and minimum dry bulb readings and humidities for 65 stations for a period of from 20 to 30 years. Saturation deficits calculated from these figures are set out in Table 1.

Monthly maximum and minimum temperatures and humidities for individual years for Charleville, Cloncurry and Longreach.

(iii.) Records of evaporation from a free water surface from five stations, viz., Winton, Blackall, St. George, Charleville and Warwick. These are given in Table 2.

Table 2.

Relationship between saturation deficit and measured evaporation for five Queensland stations.

Station.	Value.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
Winton	S.D.	·72	·61	·56	·50	·36	·26	·26	·36	·51	·67	·76	·78
	E.	12·14	9·22	9·29	7·38	5·74	4·06	4·28	5·96	8·02	10·17	10·96	12·14
	k	16·9	15·1	16·6	16·7	16·0	15·6	16·5	16·5	15·7	15·2	14·4	15·6
Blackall	S.D.	·67	·57	·49	·41	·26	·18	·19	·27	·39	·56	·63	·68
	E.	10·85	8·55	8·12	6·17	4·35	2·96	3·12	4·51	6·36	8·85	9·81	10·88
	k	16·2	15·0	16·6	15·0	16·7	16·5	16·4	16·7	16·3	15·8	15·6	16·0
Charleville	S.D.	·65	·58	·48	·37	·23	·14	·15	·24	·35	·49	·59	·64
	E.	10·70	8·80	8·18	6·13	4·19	2·65	2·71	4·00	5·89	7·99	9·21	10·29
	k	16·5	15·2	17·1	16·6	18·2	18·8	18·1	16·7	16·8	16·3	15·6	16·1
St. George	S.D.	·61	·50	·40	·31	·21	·13	·12	·19	·27	·40	·48	·51
	E.	10·29	8·79	8·02	5·35	3·52	2·33	2·34	3·46	5·46	7·90	8·93	9·94
	k	16·9	17·5	20·0	17·2	16·7	17·9	19·5	18·2	20·2	19·7	18·6	19·5
Warwick	S.D.	·32	·29	·26	·19	·14	·09	·09	·13	·19	·27	·30	·34
	E.	7·22	5·97	5·75	4·05	2·89	1·98	1·99	2·69	3·98	5·60	6·41	7·21
	k	22·5	20·6	22·1	21·3	20·6	22·0	22·0	20·7	20·9	20·7	21·3	21·2

S.D.—Saturation Deficit. E.—Measured Evaporation in inches. k—constant (in equation $E = k \times S.D.$).

METHODS.

Temperature.

Mean minimum temperatures for June-July were plotted for all stations and isolines drawn (Figure 1). Mean monthly maximum temperatures for January-February were treated similarly.

The number of months having an average maximum temperature of more than 95°F. was calculated for each station for which data were recorded and the results were plotted on the map shown in Figure 2.

Rainfall Distributions.

Histograms showing the frequency distribution of monthly rainfalls were compiled with class intervals of 0·25 inch. Coefficients of variations for mean monthly rainfalls of a number of stations were calculated.

P/E Ratios.

The lack of data, particularly of daily or weekly rainfalls, made it necessary to work on a monthly basis. With evaporation records so few and so widely distributed it was impossible to attempt any detailed mapping on the basis of recorded evaporation and some method of calculating or estimating evaporation from available data had to be evolved. Davidson's (1935) method of conversion expressed as the formula $E = k \times S.D.$ was used and, to find a value for K (mean monthly), evaporation figures for five stations were compared with values for saturation deficits calculated from records of temperature and relative humidity. In these calculations temperatures used were $\frac{\text{Max.} + \text{Min.}}{2}$ and relative humidities those at 9 a.m.

Table 2 gives a comparison of monthly evaporations and calculated saturation deficits for the five inland stations in Queensland. Values of k range from 14.9 to 21, but most of them are about 16 (coastal about 22). It was considered that in a preliminary study such as this the use of a single value of k is justified. Accordingly figures for saturation deficit were converted to evaporation figures by multiplying by 16. The chief reason for converting saturation deficit to evaporation instead of using Meyer ratio $\frac{P}{S.D.}$ was to have both precipitation and evaporation in the same unit, namely, inches.

Monthly evaporation figures for the 65 stations were computed from the calculated values for saturation deficit. Examination of the frequency distribution charts of mean monthly rainfall as well as evaporation figures showed that the months could be grouped in pairs beginning with October-November, thus dividing the year into six periods, each of two months. Bi-monthly P/E ratios were then calculated and maps for each two-monthly "season" are given as Figures 3-8.*

* *Marginal Errors.*—In drawing charts of a limited area, especially one with arbitrary boundaries such as Queensland, there is always the possibility of marginal error. Such error can be minimized by plotting relevant data on stations outside the region being studied. Without such data the correct direction of isolines at and near the margins cannot be determined with certainty.

In order to reduce marginal error, data were plotted for coastal stations using the same values of k as for the inland stations. It must be emphasized that the coastal data are not exhaustive and the isolines shown on the maps do not represent the complete picture. Further detailed study is needed in the agricultural regions of the coastal belt. Although they are outside the scope of the present paper, the small amount of work which has been done indicates that the methods outlined here should yield useful results if applied to the dense network of stations of the coastal regions.

Along the western and southern borders the possibility of marginal error is greater. Detailed reports from stations in New South Wales, South Australia and Northern Territory were not available. The direction of isolines along these margins is only approximate.

P/E Differences.

A review of the frequency distribution charts of mean monthly rainfall showed that in semi-arid Queensland rainfall occurs in two well-marked seasons:

(1) Summer season (January, February and March);

(2) Winter season (June and July).

Rainfall in the summer season is far greater than in winter. Falls do occur in other months—notably October, November and December—but these are usually storms of erratic distribution and rarely represent general rain. It is generally believed that winter rainfall is more reliable in the south and becomes negligible towards the north.

In an attempt to fix the northern limits of effective winter rainfall the differences between January-February-March P/E and June-July P/E ratios were plotted and isolines drawn at intervals of 0.1 (Figure 9).

South of the zero line, P/E for winter exceeds P/E for summer; north of the line summer P/E is the greater. Maps were also drawn showing the differences between the following groups of months:

(1) February-March—June-July.

(2) December-January—June-July.

In these, the lines followed the same general pattern as in Figure 4 and the position of the zero line was approximately the same.

In order to test the consistency of the general pattern for different seasons over individual years, 11-year and 23-year averages of the summer minus winter P/E values were calculated for the three centres for which these data were available.

Seasonal Distribution and Reliability of Effective Rainfall.

Examination of Queensland data in the light of known conditions in the field indicated that for summer months Trumble's (1939) figure of 0.3 (for a P/E value) as being indicative of "a period of influential rain" is too high, because good growth of pastures may take place when monthly P/E values are less than 0·3. Trumble (1939) defined "a period of influential rainfall" as one in which average P/E is equal to or greater than 0.3, while for tropical Australia Lawrence (1941) used the lower value of 0.25. It was considered that for summer months both of these figures are too high; good growth of pastures can take place during months in which average P/E is less than 0·3 or 0·25. In addition, as Trumble (1939) pointed out, Queensland rainfall is more variable than that of southern States, where the period of minimum evaporation coincides with the period of maximum precipitation. In Queensland, precipitation and evaporation figures tend to run parallel and evaporation is high during the month of maximum precipitation. Under such conditions, a lower value for P/E ratio might be adopted as the criterion of a "period of influential rain." Tentative tests of lower values indicated that for summer a wet month—i.e., month of effective rainfall—could be defined as one with a P/E equal to or greater than 0·2. Accordingly this value was used for the period October to March. In winter the figure of 0·3 was found to agree fairly well with observed field conditions, and this was used for the months from April to September. It must be emphasized that this lower figure is purely arbitrary and has not been reached as the result of any experimental work on rate of loss of moisture from soils, but field observations indicate that it approximates the P/E value which will initiate and sustain growth of natural vegetation.

Except for Cloncurry, Longreach and Charleville, data for saturation deficit were available only in the form of monthly means for the whole period on record. This made it impossible to calculate individually the actual P/E ratio for each month. It was believed that, as variability of evaporation was small compared with that of rainfall, it might be possible to use average values for evaporation combined with individual figures for rainfall without introducing any very great error.

To test this, the number of wet months was determined for the three stations, using (1) ratio of precipitation to evaporation, the latter being obtained by calculation from actual values for saturation deficit for each month; and (2) ratio of precipitation to evaporation, in which evaporation figures were calculated from mean values of saturation deficit for the whole period on record.

Table 3.

Comparison of two methods of computing P/E.

PERCENTAGE OF YEARS IN WHICH MONTHS RECEIVE AN EFFECTIVE RAINFALL.

Station.	Oct.–Nov.		Dec.–Jan.		Feb.–Mar.		Apr.–May.		June-July.		Aug.–Sept.	
	Ind. E.*	Av. E.†	Ind. E.	Av. E.	Ind. E.	Av. E.	Ind. E.	Av. E.	Ind. E.	Av. E.	Ind. E.	Av. E.
Cloncurry	16	8	50	54	66	66	12	4	20	12	0	0
Longreach	21	19	47	41	52	55	27	18	42	42	6	6
Charleville	38	41	60	63	51	51	25	25	70	70	28	28

* Ind. E. — Percentage of years in which months receive an effective rainfall, taking evaporations for individual years.

† Av. E. — Percentage of years in which months receive an effective rainfall, taking a mean evaporation figure for all years.

The comparison is set out in Table 3. It shows that the mean saturation deficit may be used for computing evaporation without materially affecting the results.

Zonation.

Zonation was based on the three factors which were considered to be most important in the study of a pastoral environment, viz:—(1) effective rainfall; (2) distribution of rainfall; (3) reliability of rainfall. In addition it was felt that where necessary consideration could be given to the mean annual rainfall.

From the distribution and reliability studies Figures 10, 11 and 12, showing the number of wet months in summer and winter in 50, 66 and 75 per cent. respectively of all years recorded, were drawn.

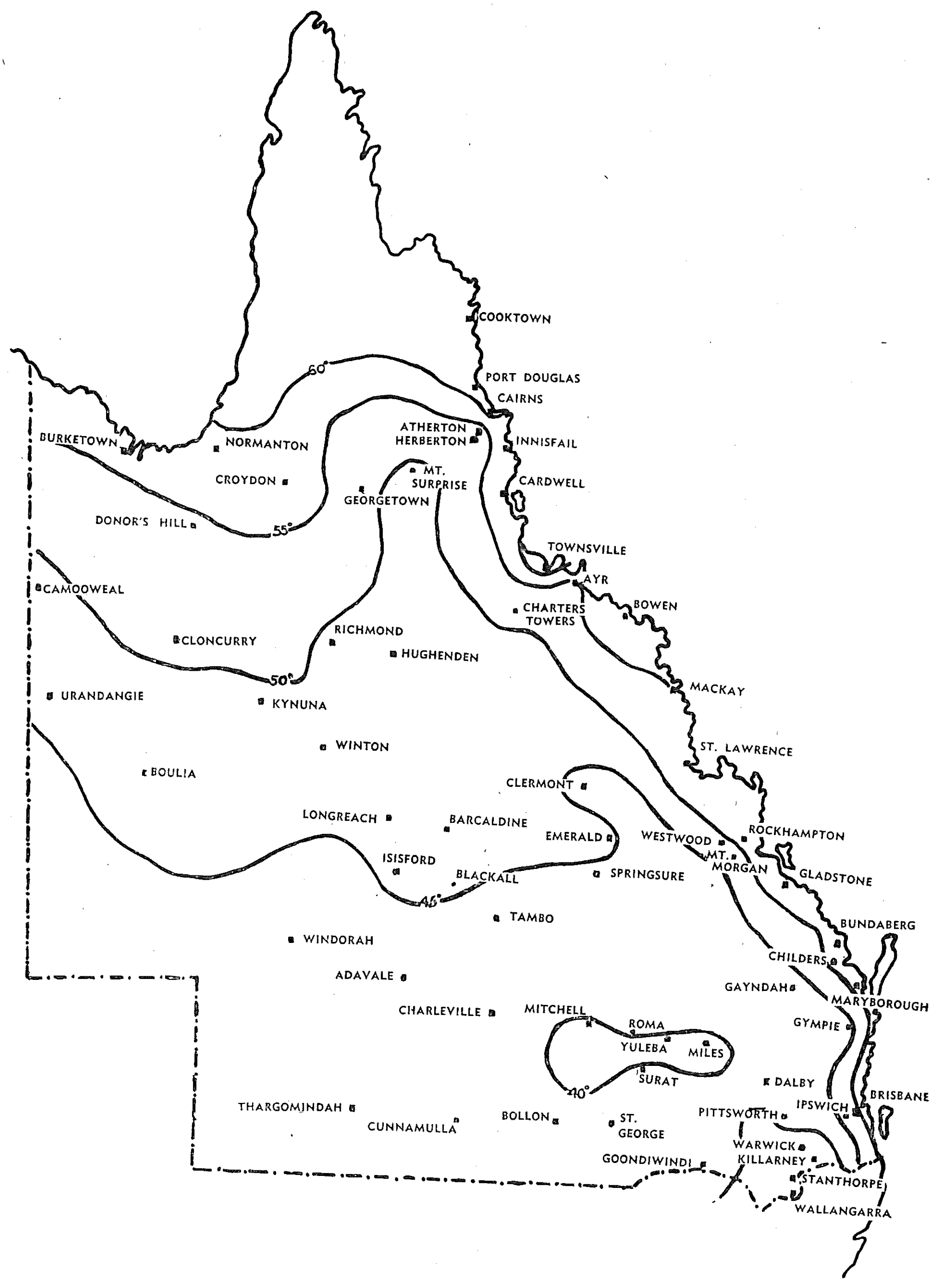


Figure 1.
Map showing mean minimum temperatures for the months of June and July.

Areas having 6, 4, 2 or 0 wet summer months in 50 per cent. of the years are given the indices $\frac{A}{50}$, $\frac{B}{50}$, $\frac{C}{50}$ and $\frac{D}{50}$, while for winter a, b, c, and d, are used in a similar manner. An area receiving effective rain in six summer months and six winter months (though not necessarily in the same year) in 50 per cent. of years studied is denoted by $\frac{Aa}{50}$. A zone having four months of effective rain in the summer and two months of effective rain during the winter in 50 per cent. of the years is denoted by $\frac{Bc}{50}$.

Likewise, on the map showing the conditions for 66 per cent. and 75 per cent. of the years, the index used for an area having six summer and four winter months during which effective rain fell is classified as $\frac{Ab}{66}$ or $\frac{Ab}{75}$.

At the same time consideration has been given, where necessary, to the mean annual rainfall, by prefixing this figure to the index classification. For example, Camooweal and Isisford are both in the zone $\frac{Cd}{66}$, but the mean annual rainfall at the former is 14.89 inches and at the latter 17.85 inches. These centres can be differentiated as $15\frac{Cd}{66}$ for Camooweal and $18\frac{Cd}{66}$ for Isisford.

Table 4 shows, for each of the stations considered, the zonation index for each order of reliability, as well as mean annual rainfall, mean maximum summer and minimum winter temperatures, and number of months having a mean maximum temperature equal to or greater than 95°F.

RESULTS.

Temperature.

The map showing mean minimum temperatures for June and July (Figure 1) is characterized by isolines which, in the inland area, run more or less east-west. In the east they are modified by ranges and proximity of the sea. Around Mitchell, Yuleba and Surat is a peculiar cold closed zone within the 40°F. isotherm.

It is considered that Queensland maximum summer temperatures are not at any time high enough to inhibit appreciably the growth of plants and consequently the map showing these isolines is not published.

Figure 2, showing the number of months having a mean maximum temperature of more than 95°F., exhibits a closed area around Kynuna, Richmond and Winton in which six months exceed the above value. The zone which has five hot months is of somewhat greater dimensions, extending from Croydon in the north to a point west of Longreach in the south, and including Donor's Hill, Cloncurry, Camooweal, Urandangie, and Boulia.

The line forming the boundary of the zone, which has four hot months, runs more or less east from the border north of Camooweal, turning south near Croydon, and again assuming an east-west direction from Blackall to the South Australian border. It includes the districts of Hughenden, Longreach, Isisford, Blackall and Windorah.

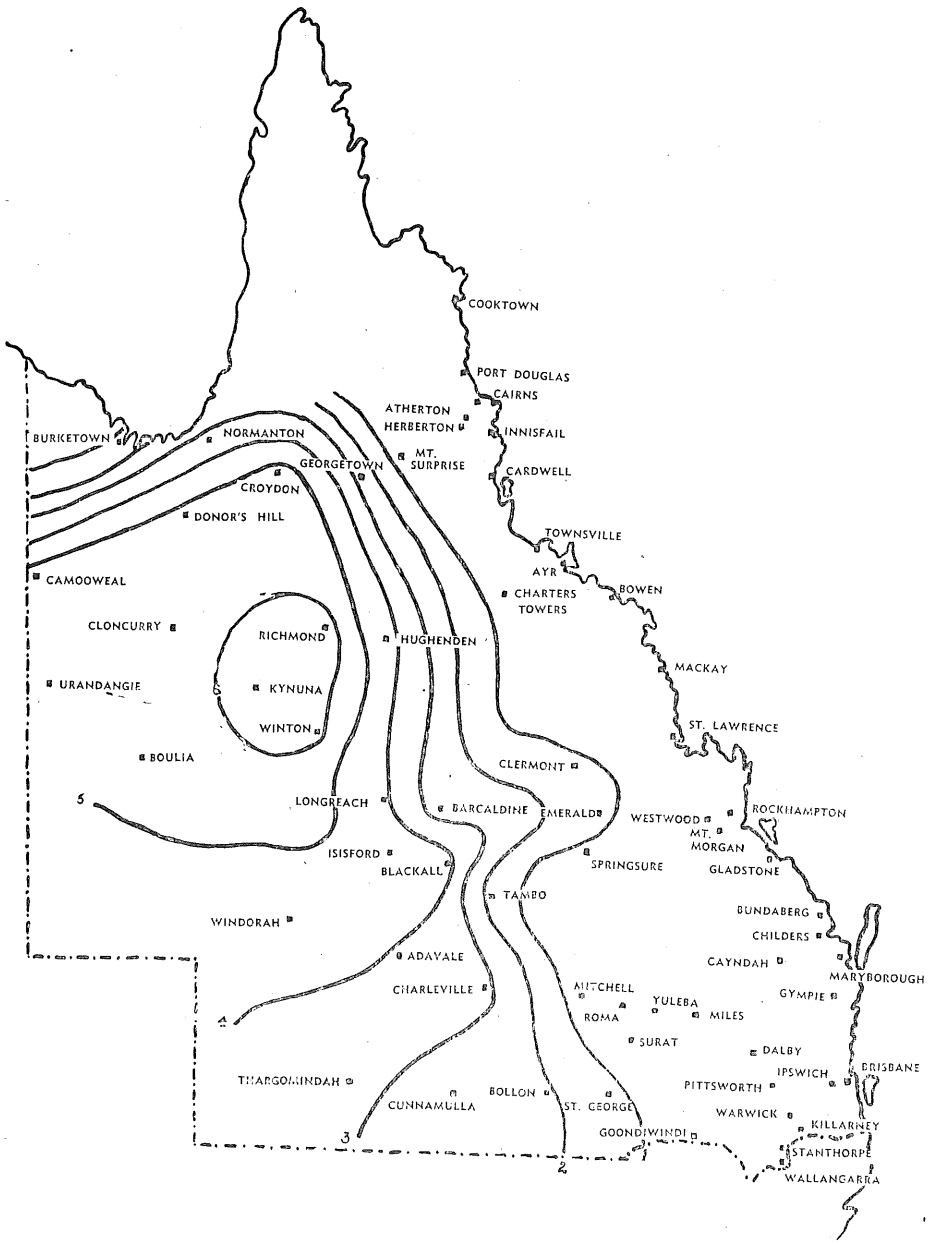


Figure 2.

Map showing the mean number of months with mean maximum temperature 95°F. or greater.

The western limits of the 6-months line are somewhat indefinite. Camooweal, Cloncurry and Urandangie have a sixth month in which the mean maximum temperatures are 94·8°, 94·6° and 94·7° respectively.

The lines bounding the other zones follow approximately the same pattern with a progressively decreasing tendency to run east-west in the southern districts.

The area in which the mean maximum temperature does not exceed 95°F. in any month extends as far west as Mt. Surprise and Charters Towers in the north, while towards the south it includes the Springsure, Mitchell, Surat and Goondiwindi districts.

Rainfall Distribution.

The coefficients of variations for the mean monthly rainfalls were of the order of 0·9 and accordingly were considered unsatisfactory. The histograms are not reproduced here but they were studied in detail before commencing work on the seasonal distribution and reliability of effective rainfall.

Table 4.

Zonation indices and other data for 65 Queensland stations.

Station.	Ind. 50% *	Ind. 66% †	Ind. 75% ‡	Mean Annual Rainfall. Inches.	Jan.–Feb. Mean Max. Temp. °F.	June–July Mean Min. Temp. °F.	No. of Months with Mean Max. T. > 95° F.
Burketown	Bd	Bd	Bd	27·61	92·9	56·3	1
Cloncurry	Cd	Cd	Cd	17·96	97·8	52·8	5
Croydon	Bd	Bd	Bd	28·75	95·7	58·0	5
Donor's Hill	Bd	Bd	Bd	25·49	96·2	53·7	5
Normanton	Bd	Bd	Bd	37·87	93·8	59·7	3
Georgetown	Bd	Bd	Bd	31·74	92·8	54·3	3
Hughenden	Bd	Bd	Cd	19·05	96·2	48·0	4
Mount Surprise ..	Bd	Bd	Bd	30·28	90·7	49·7	0
Richmond	Bd	Cd	Cd	18·08	97·6	48·6	6
Atherton	Aa	Bb	Bb	53·75	83·2	50·8	0
Herberton	Ab	Ab	Ab	43·80	81·6	50·2	0
Cairns	Aa	Ab	Ab	88·75	89·5	62·4	0
Cooktown	Ab	Bb	Bb	69·32	88·6	67·0	0
Port Douglas ..	Ab	Ab	Ab	79·66	86·2	63·4	0
Cardwell	Aa	Ab	Ab	82·38	87·7	56·0	0
Innisfail	Aa	Aa	Aa	143·78	87·4	58·5	0
Townsville	Bc	Bc	Bd	45·72	87·1	60·8	0
Ayr	Bc	Bc	Bc	41·54	89·2	54·7	0
Bowen	Bc	Bc	Bc	39·30	87·8	58·0	0
Mackay	Ab	Ab	Bb	66·91	85·7	54·7	0
St. Lawrence ..	Ab	Ab	Ac	41·11	87·9	52·5	0
Charters Towers ..	Bc	Bd	Bd	24·64	91·7	52·8	0
Blackall	Bc	Cc	Cd	20·77	98·1	44·6	4
Clermont	Ac	Bc	Bc	26·97	92·5	44·4	1
Emerald	Bc	Bc	Bc	24·61	93·6	45·7	1
Springsure	Ac	Bc	Bc	26·19	92·3	44·3	0
Tambo	Bc	Bc	Cc	21·00	95·0	40·5	1
Barcaldine	Bc	Cc	Cd	19·70	95·4	46·5	2
Isisford	Cc	Cd	Cd	17·73	98·2	45·4	4
Longreach	Cc	Cd	Cd	16·52	98·3	45·4	4

Table 4—continued.

Zonation indices and other data for 65 Queensland stations—*continued.*

Station.	Ind. 50% *	Ind. 66% †	Ind. 75% ‡	Mean Annual Rainfall. Inches.	Jan.–Feb. Mean Max. Temp. °F.	June–July Mean Min. Temp. °F.	No. of Months with Mean Max. T. > 95° F.
Camooweal	Cd	Cd	Cd	14·96	97·7	48·9	5
Kynuna	Cd	Cd	Cd	15·71	99·1	46·9	6
Urandangie	Dd	Dd	Dd	10·64	100·1	46·4	5
Winton	Cd	Cd	Cd	15·90	99·4	47·2	6
Boulia	Dd	Dd	Dd	10·34	100·7	46·8	5
Windorah	Dd	Dd	Dd	11·26	99·7	44·2	4
Bundaberg	Aa	Ab	Ab	43·47	85·8	50·3	0
Childers	Aa	Ab	Ab	41·78	87·1	51·0	0
Gayndah	Ab	Ab	Ac	30·44	89·8	43·0	0
Gladstone	Ab	Ab	Ac	39·98	85·3	53·7	0
Mount Morgan ..	Ab	Ab	Ac	32·19	87·6	48·7	0
Rockhampton ..	Ab	Ac	Ac	38·95	88·8	52·1	0
Westwood	Ab	Ac	Ac	29·32	89·2	45·6	0
Brisbane	Aa	Aa	Aa	44·72	84·9	50·0	0
Gympie	Aa	Aa	Ab	45·42	87·7	44·6	0
Ipswich	Ab	Ab	Ab	33·07	89·3	45·1	0
Maryborough ..	Aa	Ab	Ab	45·63	86·8	49·1	0
Dalby	Ab	Ab	Ab	26·12	89·0	40·8	0
Goondiwindi ..	Bb	Bb	Bb	24·05	92·8	42·1	0
Pittsworth	Ab	Ab	Ab	27·22	85·3	42·2	0
Stanthorpe	Aa	Aa	Aa	29·52	81·0	34·9	0
Wallangarra	Aa	Aa	Aa	29·48	79·3	37·6	0
Warwick	Aa	Ab	Ab	27·49	85·2	38·9	0
Killarney	Aa	Aa	Aa	28·55	84·1	37·0	0
Miles	Ab	Bb	Bc	25·63	91·5	39·6	0
Mitchell	Bb	Bc	Bc	23·00	91·9	38·6	0
Roma	Bb	Bc	Bc	23·08	93·3	40·2	0
St. George	Bb	Bc	Cc	19·65	95·2	41·6	1
Surat	Bb	Bb	Bc	22·69	93·9	40·7	0
Yuleba	Ab	Bb	Bc	24·47	92·1	37·0	0
Bollon	Cc	Cc	Cc	17·62	95·6	40·8	2
Charleville	Bb	Cc	Cc	19·38	96·2	41·2	3
Cunnamulla	Cc	Dc	Dc	14·11	96·1	42·9	2
Adavale	Cc	Dd	Dd	15·38	98·0	42·5	3
Thargomindah ..	Dd	Dd	Dd	10·56	97·1	43·7	3

* Ind. 50% — Zone in which station is situated on map showing the number of wet months in 50% of years on record.

† Ind. 66% — Zone in which station is situated on map showing the number of wet months in 66% of years on record.

‡ Ind. 75% — Zone in which station is situated on map showing the number of wet months in 75% of years on record.

Precipitation-Evaporation Ratios.

Figures 3-8, drawn from the rainfall evaporation ratios for the six two-monthly seasons, presented the following features:—

October-November: The late spring is normally a dry season, so the isolines are few and well spaced. They trend roughly north-south.

December-January: Early summer shows a marked change in both number and direction of the isolines. In this season the isolines are roughly parallel to the coastline.

February-March: The isolines in the main summer rainfall season are very similar to those of December-January, except that the lines are further towards the south-west.

April-May: The autumn season shows another marked change in the configuration of the lines. The lines are few and well spaced. A curious feature is the dry tongue which extends into the Lockyer and Fassifern Valleys (west of Brisbane) from the north-west. The general trend of the lines is north-south.

June-July: The isolines in the winter map are more numerous and more closely spaced. This is a reflection of the higher rainfall normally experienced in this season. The dry tongue apparent on the April-May map is well developed and is accentuated by a moist area further west. This extends from Warwick to Mitchell. A study of the synoptic weather charts for several years indicates that during winter cold fronts are frequently retarded east of Charleville. This area of retardation coincides very closely with the position of the moist tongue shown on the June-July P/E map. The general trend of the lines is north-south.

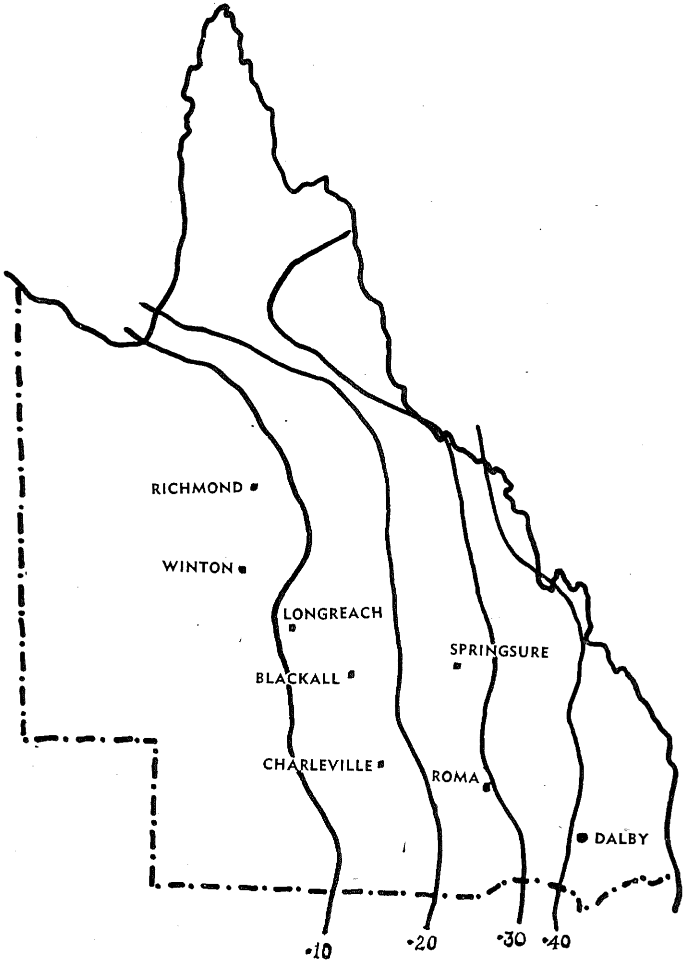
August-September: In early spring the pattern of lines is similar to that of October-November. Some evidence remains of the dry tongue noted on the two previous maps but almost all the lines trend north-south.

P/E Difference Map.

The zero line on the summer-winter P/E map extends through Isisford towards Barcaldine, then east almost to Emerald. From Emerald it dips sharply southward to about latitude 25.5° S., then swings eastward to Taroom. From Taroom it extends in a south-easterly direction to about Ipswich.

North and east of the zero line, P/E for summer is greater than P/E for winter; south and west of the line the reverse applies.

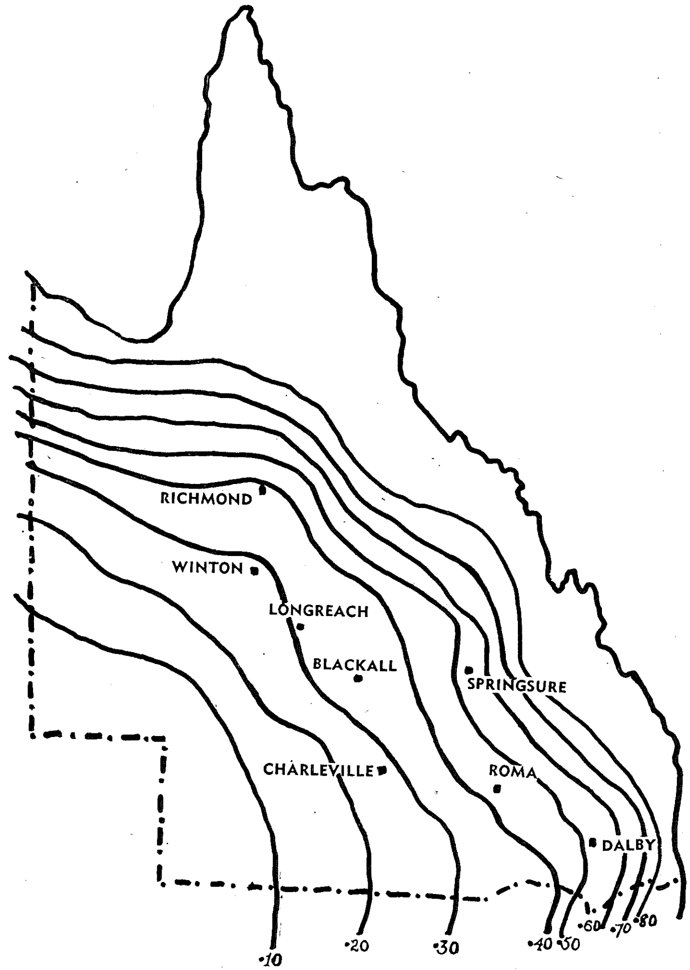
The moist tongue in southern Queensland noted in the June-July P/E map is reflected in the P/E difference map.



A

Figure 3.

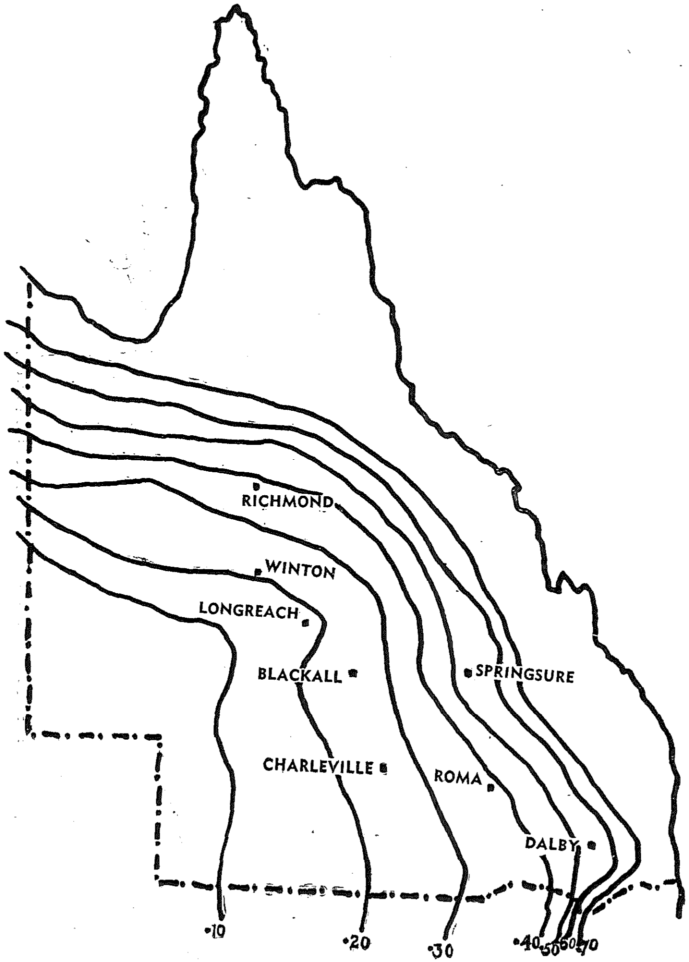
Map showing isolines of P/E values for the two-monthly period October-November.



B

Figure 4.

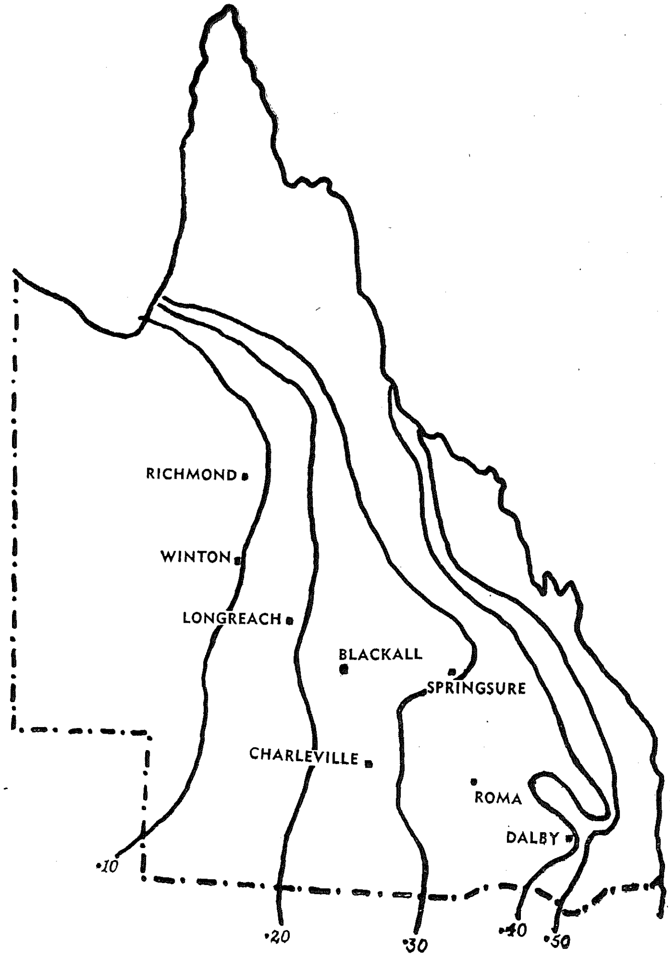
Map showing isolines of P/E values for the two-monthly period December-January.



C

Figure 5.

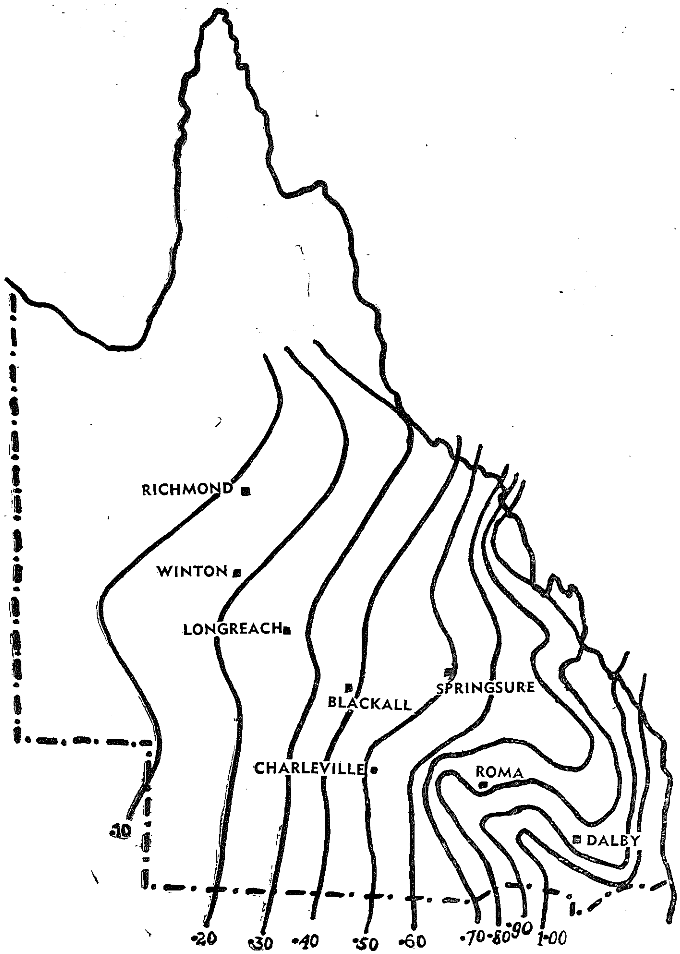
Map showing isolines of P/E values for the two-monthly period February-March.



D

Figure 6.

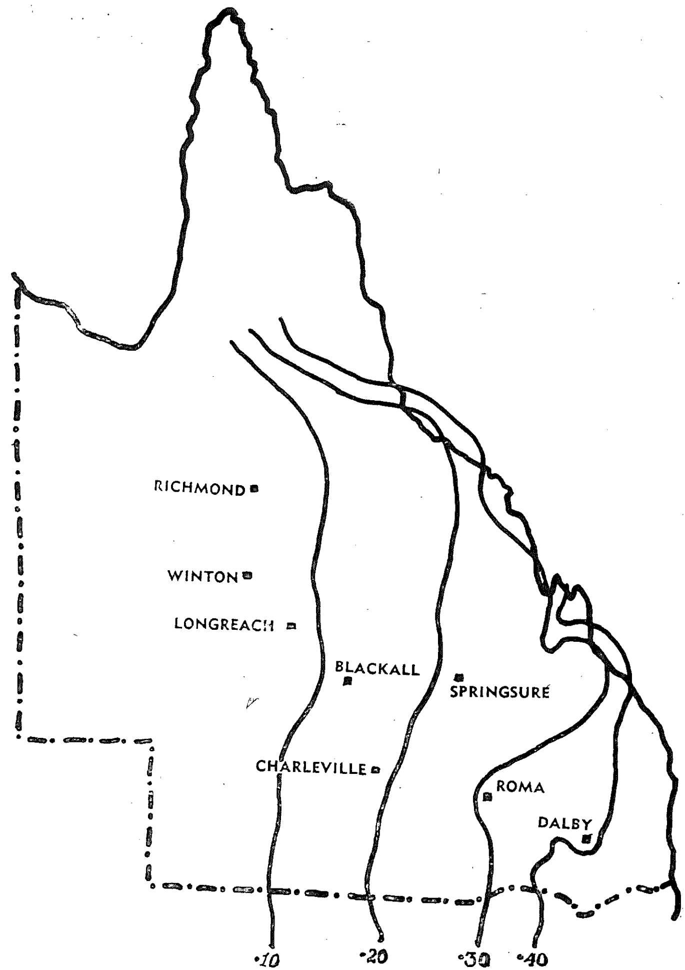
Map showing isolines of P/E values for the two-monthly period April-May.



E

Figure 7.

Map showing isolines of P/E values for the two-monthly period June-July.



F

Figure 8.

Map showing isolines of P/E values for the two-monthly period August-September.

As might be expected, the low rainfall reliability did not permit the isolines shown in Figure 9 to apply to each individual year; in fact, in some years a marked departure was shown. The 11-year means showed closer agreement and the 23-year means gave a reasonably close correlation.

For Charleville, Longreach and Cloncurry, for instance, where the mean summer—winter P/E values are $-\cdot29$, $+\cdot07$ and $+\cdot26$ respectively, the number of 23-year periods with various mean values are as shown below:—

Charleville.		Longreach.		Cloncurry.	
Mean Value.	No. of Periods.	Mean Value.	No. of Periods.	Mean Value.	No. of Periods.
−·23	2	+·04	1	+·23	1
−·27	2	+·05	1	+·24	4
−·28	1	+·06	3	+·25	2
−·29	(mean) 4	+·07	(mean) 1	+·26	(mean) 4
−·30	1	+·08	1	+·29	1
−·31	1	+·09	1		
−·32	2	+·10	1		
−·35	1	+·11	1		
−·37	1	+·13	3		

SEASONAL DISTRIBUTION AND RELIABILITY OF EFFECTIVE RAINFALL.

From a study of seasonal distribution and reliability of periods of effective rain it was found possible to divide pastoral Queensland into a number of zones. These are shown in Figures 10, 11 and 12. Rainfall of at least 66 per cent. reliability is considered to be a minimum requirement for production from sheep under pastoral conditions.

The boundaries of all zones are approximate. Where a boundary line passes between two recording stations it is possible to place the line anywhere between them. In some cases—for example, in the eastern boundary of zone "Dd"—this may introduce a possible error of ± 100 miles. Although boundaries are shown on the maps as lines they are actually broad transition strips.

Zone Dd.

The reliability of the effective rain for any of the two-monthly periods into which the year was divided is less than 66 per cent. for the zone $\frac{\text{Dd}}{66}$. The eastern boundary of the zone extends from south of Camooweal through Boulia, Jundah and Adavale districts into northern New South Wales.

The eastern boundaries of these zones when considered on the 75 per cent. and 50 per cent. reliability levels follow approximately the same course as $\frac{\text{Dd}}{66}$.

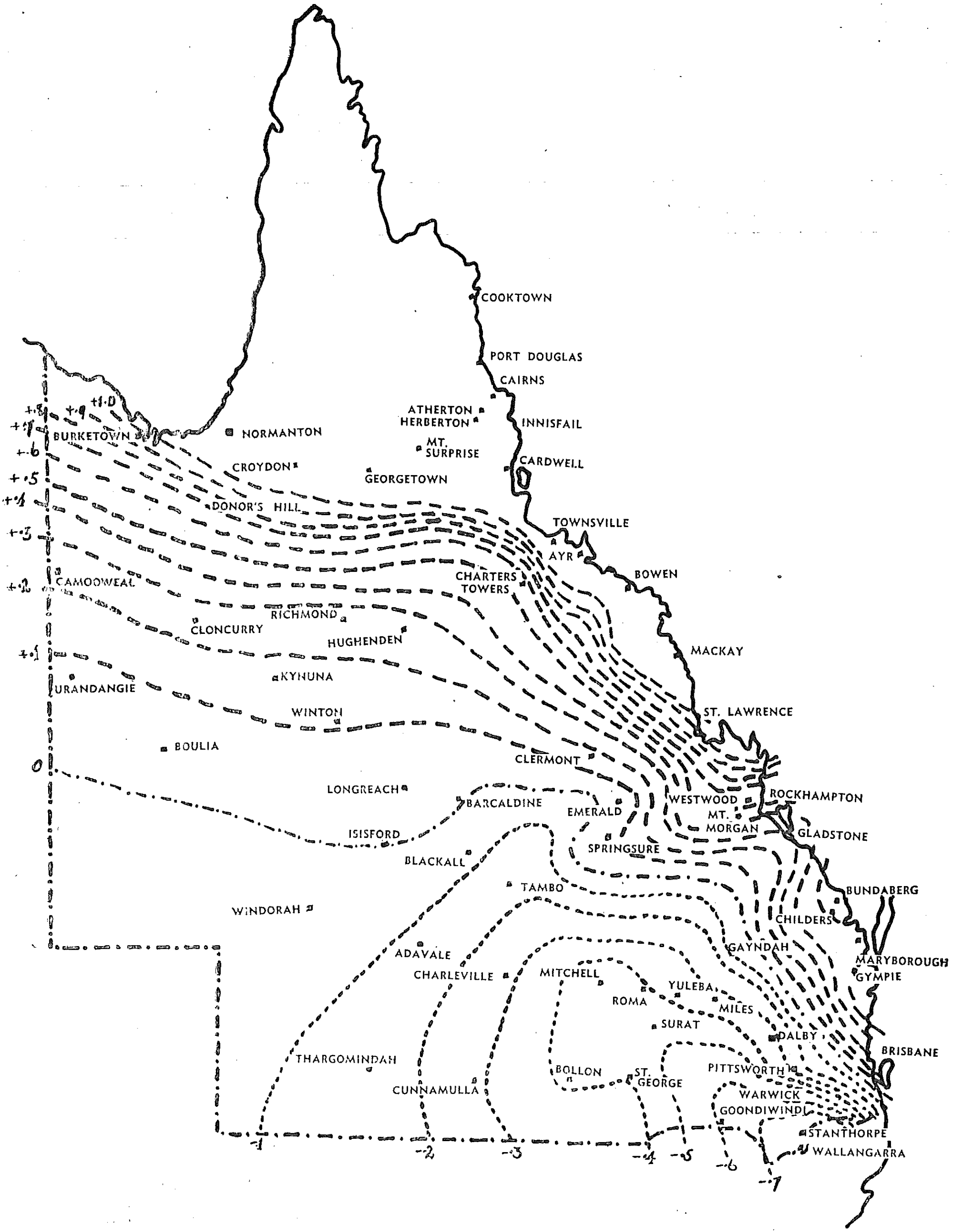


Figure 9.
Map showing difference of P/E values for periods January-February-March and June-July.

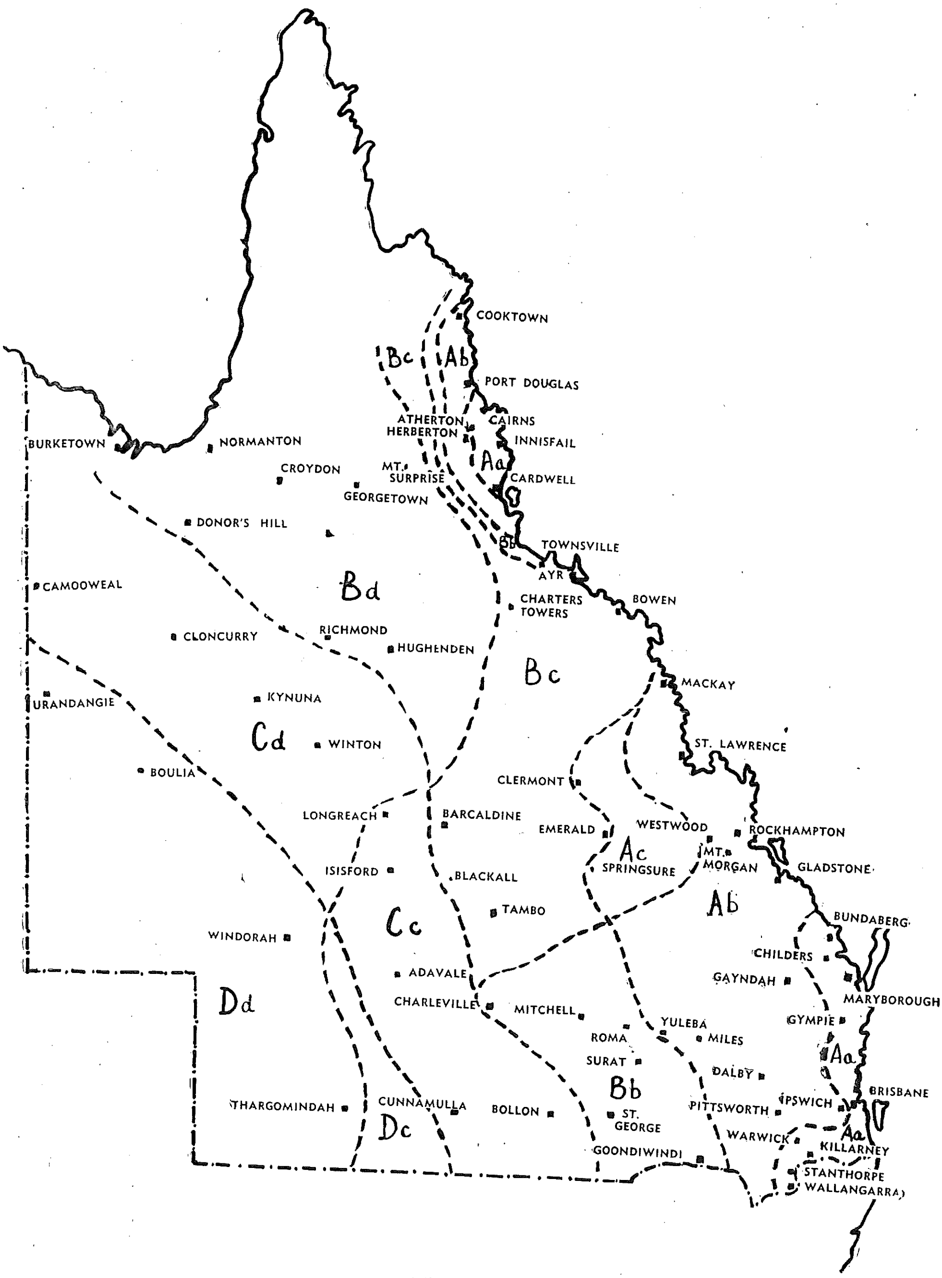


Figure 10.

Map showing zonation based on the number of wet summer and winter months in 50% of the years on record.

A and a indicate 6 wet summer and 6 wet winter months respectively.
B and b indicate 4 wet summer and 4 wet winter months respectively.
C and c indicate 2 wet summer and 2 wet winter months respectively.
D and d indicate 0 wet summer and 0 wet winter months respectively.

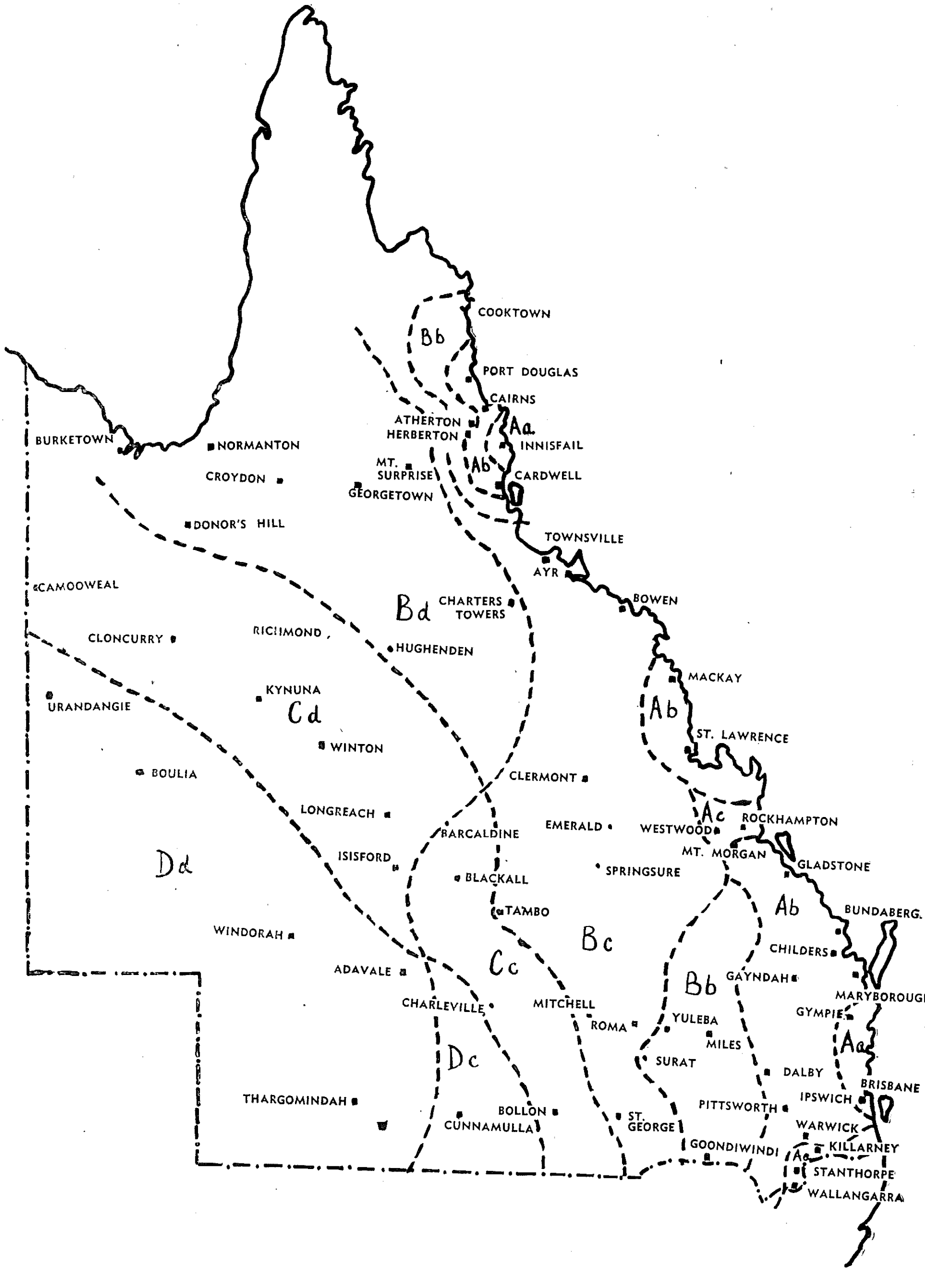


Figure 11.

Map showing zonation based on the number of wet summer and winter months in 66% of the years on record. For legend see Figure 10.

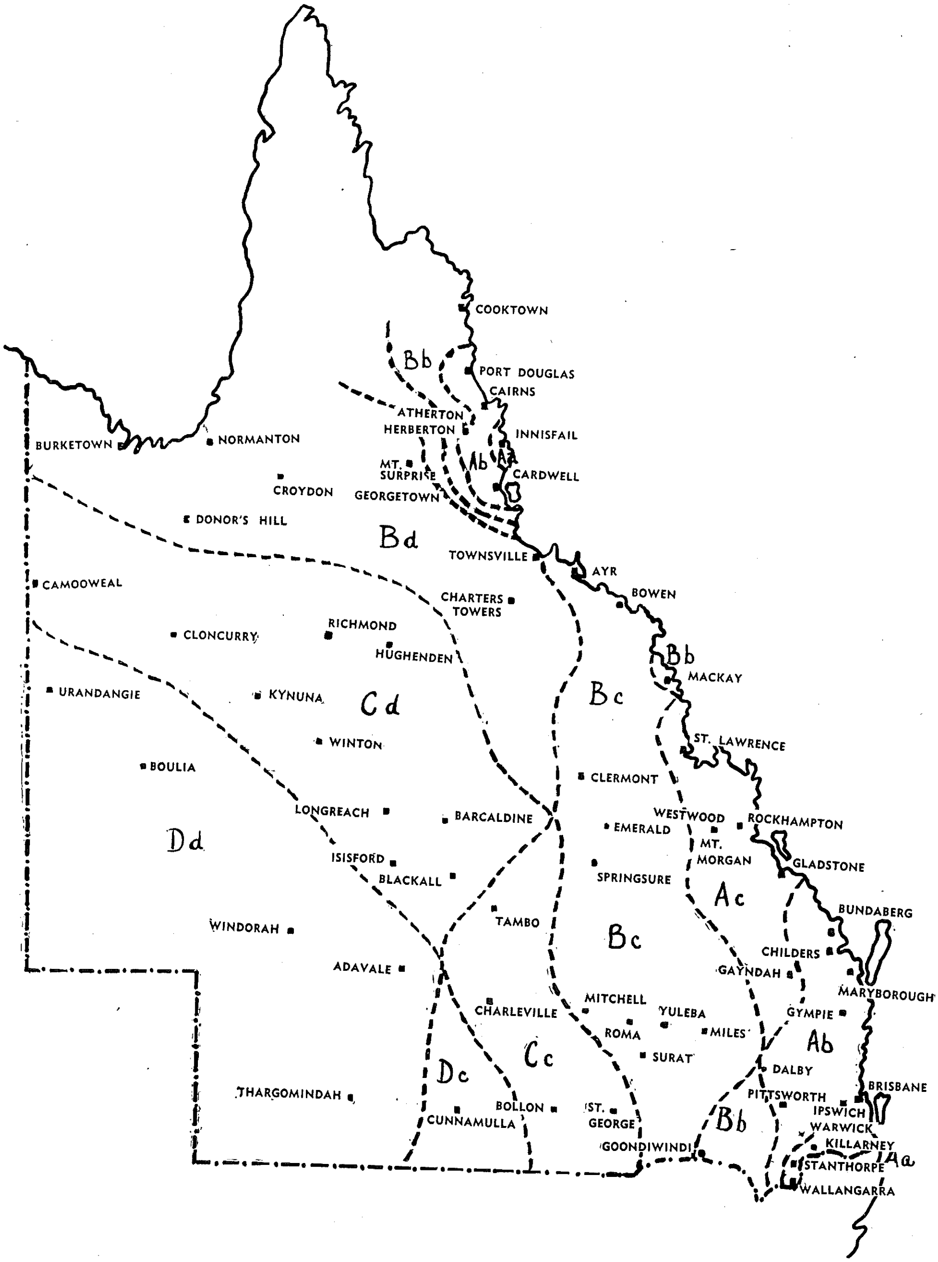


Figure 12.

Map showing zonation based on the number of wet summer and winter months in 75% of the years on record. For legend see Figure 10.

Zone Dc.

Zone $\frac{Dc}{66}$, which extends from the Cunnamulla district northwards towards Adavale, is an area remarkable in that it is the only zone in Queensland where the period of effective winter rains is more reliable than the period of effective summer rains.

When considered on a basis of 75 per cent. reliability it is seen that the apex of this triangle retreats to the south, but on a 50 per cent. reliability the importance of the summer rains increases and some of the area is included in the zone $\frac{Cc}{50}$.

Zone Cd.

Zone $\frac{Cd}{66}$ includes Camooweal, Cloncurry, Richmond, Kynuna, Winton, Longreach, Isisford, and part of the Adavale districts.

When considered on a 75 per cent. basis this zone extends eastwards to include Hughenden, Barcaldine and Blackall. On a basis of 50 per cent. reliability the zone is narrower and includes only Camooweal, Cloncurry, Kynuna and Winton districts.

Zone Cd runs almost parallel to the coastline. South-east of about Barcaldine-Isisford it merges into Zone Cc.

Zone Cc.

Zone $\frac{Cc}{66}$ is long and narrow and continues in a direction parallel to the coastline. It includes the Blackall-Barcaldine districts and extends southwards to Charleville and Bollon.

This zone is still important when considered on a basis of 75 per cent. reliability; it commences further south, between Blackall and Tambo, and extends further east to St. George. On a basis of 50 per cent. reliability it includes Longreach, Adavale and Cunnamulla.

Zone Bd.

Zone $\frac{Bd}{66}$ is broad in the north, where it extends from Burketown to Mt. Surprise. It narrows southward, but includes Hughenden and Charters Towers and extends on to the Alice Tableland and Lake Galilee. The whole of this zone lies north of the Tropic of Capricorn.

On a basis of 75 per cent. reliability this zone extends from the Gulf of Carpentaria to the east coast of Townsville and then narrows southwards to a point west of Emerald. On a basis of 50 per cent. reliability the zone includes the whole of the area around the Gulf of Carpentaria, extends in a south-easterly direction to include Richmond and Hughenden, and narrows to a point about Aramac (42 miles north of Barcaldine).

Zone Bc.

Zone $\frac{Bc}{66}$ extends southwards from the coast in the Townsville-Bowen area. It includes Clermont, Emerald and Springsure, the greater part of the Dawson Valley, and the towns of Mitchell, Roma, Surat and St. George. When considered on a basis of 75 per cent. reliability this zone is narrower in the latitude of Springsure, but it broadens to the south to include Roma, Yuleba and Miles. South of Surat it narrows again as it approaches the New South Wales border. Taken at the 50 per cent. reliability level, the zone includes country as far west as, and to the north of, Charters Towers. To the east it extends to the coast in the Ayr-Bowen districts, then southwards and westwards to Barcaldine, Blackall and Tambo; it excludes Clermont and Springsure but includes Emerald. South of Tambo it merges into zone $\frac{Bb}{66}$.

Zone Bb.

Zone $\frac{Bb}{66}$ extends southwards from a narrow peak about Mount Morgan, and broadens to include Yuleba, Surat, Miles and Goondiwindi. When judged on a basis of 75 per cent. reliability, this zone includes only a small area of the south-western Darling Downs and another isolated small area about Mackay. When considered on a basis of 50 per cent. effective rainfall reliability the zone includes St. George, Mitchell, Roma and Charleville.

Zone Ac.

Zone $\frac{Ac}{66}$ embraces only a small area from Rockhampton westward. When considered from the point of view of 75 per cent. reliability this area extends from St. Lawrence almost to Dalby and includes Rockhampton, Westwood and Gayndah. When judged on a basis of 50 per cent. reliability the Ac zone is located further west and embraces most of the Clermont and Springsure districts.

Zone Ab.

Zone $\frac{Ab}{66}$ covers most of the agricultural regions of the south-eastern portion of the State, and extends westward to Dalby, Pittsworth and Warwick. A small isolated area about Mackay and St. Lawrence is also included in this category.

This zone, when considered on a basis of 75 per cent. reliability, is smaller and more restricted, but still includes Dalby and Pittsworth, while for 50 per cent. reliability it extends further west and embraces Yuleba and Miles.

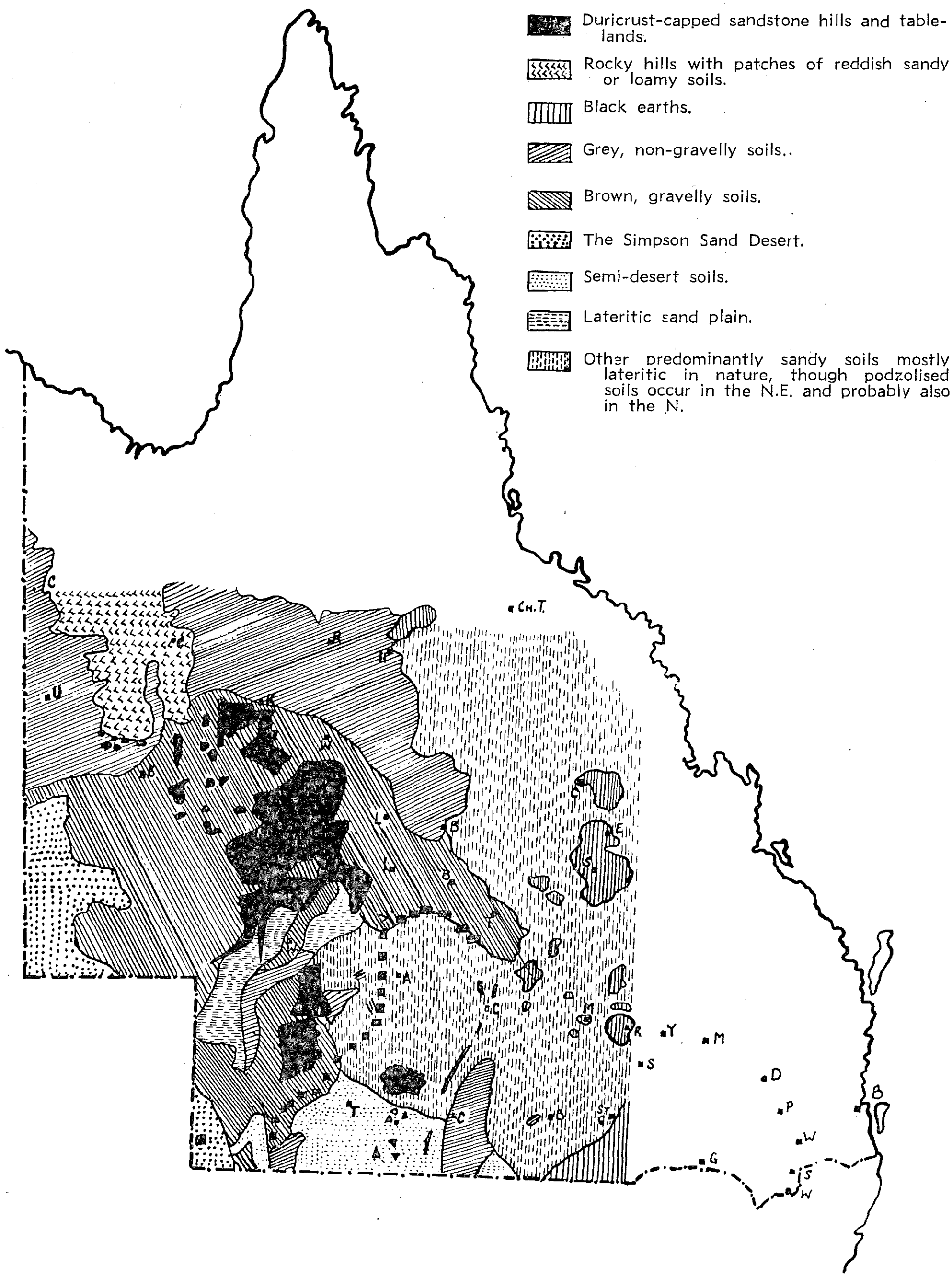


Figure 13.
Soil map of western Queensland, after Blake (1938).

DISCUSSION.

Soils and Vegetation in Relation to Climatic Factors Studied.

Prescott (1931) considered that "in Australia, there is abundant evidence that the seasonal rain factor is important in determining the soil type, characteristic soils being developed in summer and winter rainfall zones . . ." He also states that "in Queensland, the coastal plain soils developed under conditions of high rainfall, with readily permeable soils, are podsolic in character, except where red loams are developed under tropical rain forests—proceeding inland, black soils under savannah woodlands or open savannah are developed, while in the semi-arid zone browns and grey soils carrying open grassland or shrub steppe association, alternating with mulga, is to be observed reaching to the desert sandhills in the extreme west." Prescott also points out "that so far as Eastern Australia is concerned, most of the effect of a rise in temperature can be explained in terms of increased evaporation."

In the region to which these climatological studies apply, a close correlation between detailed soil type and climate is not obvious (see Figs. 13 and 14). Specific types appear to be determined largely by parent rock and subsoil drainage.

The accompanying vegetation map (Figure 14) is based on that of Blake (1938) with modifications from some of his unpublished data. The general pattern of vegetation types (grassland, woodland, &c.) depends primarily upon soil differences, though climate influences the floristic composition of the major plant formations. The distribution of individual species in relation to climate is also of interest. Mitchell grasses are dominant over large areas of brown gravelly and grey non-gravelly soils, the main species in some areas being curly Mitchell grass (*Astrebla lappacea*) and in others barley Mitchell grass (*Astrebla pectinata*). At present, the reasons for the differences in dominance of the two species of *Astrebla* are not clear. In general, barley Mitchell grass is more plentiful in the more arid regions but differences in soil also appear to play a part. The main Mitchell grass associations are to be found in climatic zone $\frac{Cd}{66}$. Other important Mitchell grass areas do occur, particularly at Dirranbandi in zone $\frac{Bb}{66}$, and on the old flood plain of the Warrego River extending southwards from Wyandra (in climatic zone $\frac{Dc}{66}$).

Climatic influence appears to be responsible for the gradual diminution in area and stature of the gidyea (*Acacia cambagei*) scrubs towards the western boundary of the Mitchell grassland. In the eastern part, such as around Blackall, gidyea occupies more land than Mitchell grass; in the western part, Mitchell grassland carries only scattered patches of gidyea. This species grows mainly within the zone $\frac{Cd}{66}$ and the northern part of zone $\frac{Cc}{66}$. Elsewhere it occurs in small communities, chiefly in depressions and along watercourses.

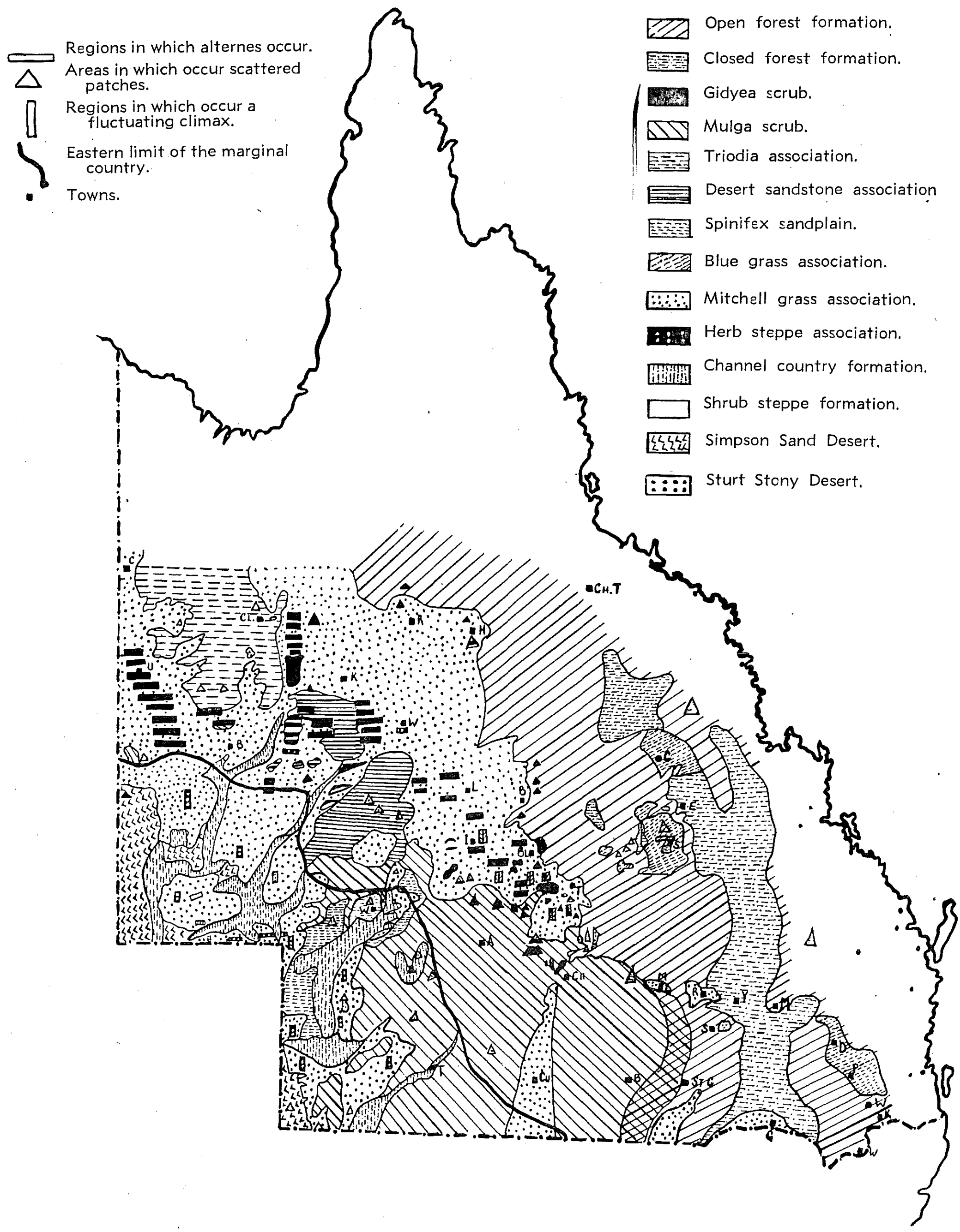


Figure 14.

Map of Queensland showing the western plant formations and major associations, from Blake (1938), with modifications from one of his unpublished maps.

Dense scrubs, somewhat similar to those in which gidyea occurs, are also formed by other Acacias, notably brigalow (*A. harpophylla*). Brigalow and gidyea overlap in many areas, but there seems to be a climatic check on the spread of the former towards the north-west and of the latter towards the south-east. Outside the zones $\frac{Bc}{66}$, $\frac{Bb}{66}$, and $\frac{Ab}{66}$, brigalow does not form dense scrubs, but occurs in patches, usually associated with gidyea. It thrives only in zones with at least two months' effective winter rainfall and reaches its maximum development in the zones with four months' effective winter rainfall. The distribution of this species is shown in Figure 15.

Despite the existence of suitable soils in the area now occupied by open eucalyptus forest, there is little development of mulga (*Acacia aneura*) east and north of zone $\frac{Cc}{66}$. The main areas of mulga in Queensland lie within zones $\frac{Dd}{66}$, $\frac{Dc}{66}$, and $\frac{Cc}{66}$. In zone $\frac{Dd}{66}$ its northward limit approximately coincides with the zero line on the P/E difference map. This indicates that, though mulga is extremely drought resistant, some winter rain is necessary for its best development. The distribution of mulga is given in Figure 16; while this species is shown in zone $\frac{Cd}{66}$, it occurs there only in small communities or as scattered individuals.

Two other Acacias—myall (*A. pendula*) and boree (*A. cana*)—are of particular interest. They grow in the same kind of soil and each occurs mainly as a fringe along the margins of scrub formations. The present known distribution of these trees in Queensland is shown in Figure 17. Myall extends as far to the north-west as Blackall and occurs in zones $\frac{Cc}{66}$, $\frac{Dc}{66}$, $\frac{Bc}{66}$ and $\frac{Bb}{66}$. It does not extend north of the zero line on the P/E difference map (Figure 9). Apparently it must have at least two months' effective rainfall in winter. Boree, on the other hand, grows mainly in the zone $\frac{Cd}{66}$ to the north and west of Blackall. It extends into the northernmost portion of $\frac{Cc}{66}$ and a narrow tongue runs southward along the eastern edge of the zone $\frac{Dd}{66}$, but many of the trees in this zone are stunted. The meeting of these two species on the zero line of the P/E difference map appears to be significant.

Another interesting plant whose distribution appears to be influenced largely by climatic conditions is limebush (*Eremocitrus glauca*), heavy stands of which occur in zones $\frac{Dc}{66}$, $\frac{Cc}{66}$, $\frac{Bc}{66}$ and $\frac{Bb}{66}$ (Figure 18). Three small isolated patches are known in zone $\frac{Cd}{66}$, and it is reported that these consist of stunted shrubs, which rarely produce fruit. In zone $\frac{Bb}{66}$ the plant is spreading so rapidly that it is regarded as a pest of pastoral lands.

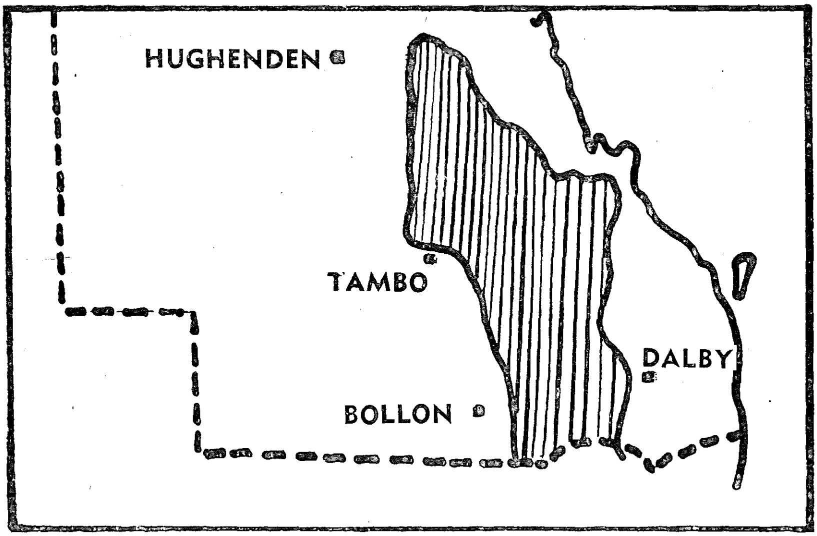


Figure 15.

Map showing the distribution of brigalow (*Acacia harpophylla*) forests. Outside the shaded area brigalow occurs as isolated clumps, usually in depressions or mixed with other species.

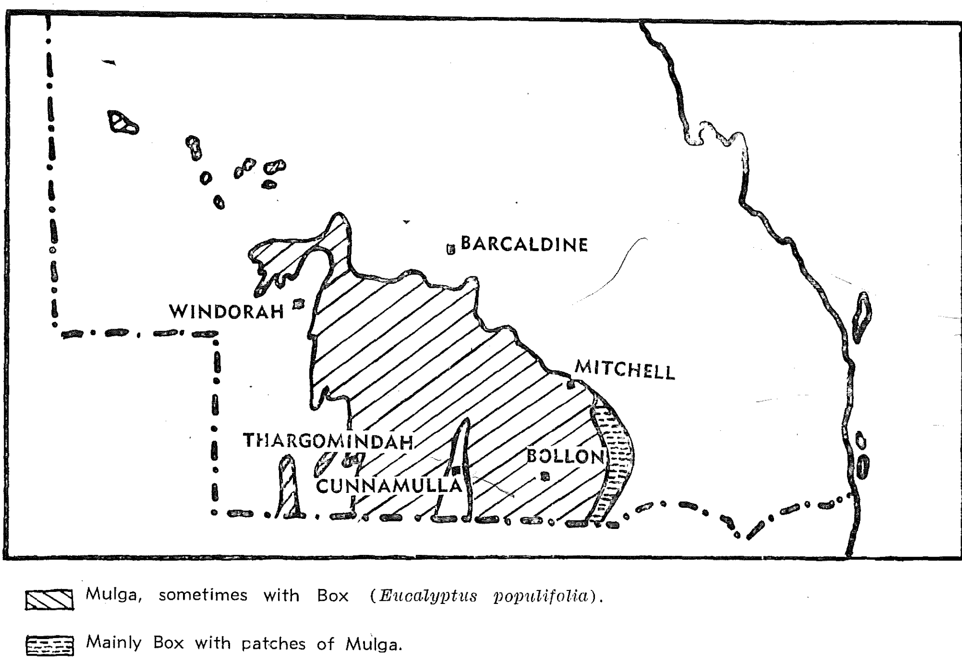


Figure 16.

Map showing the distribution of mulga (*Acacia aneura*).

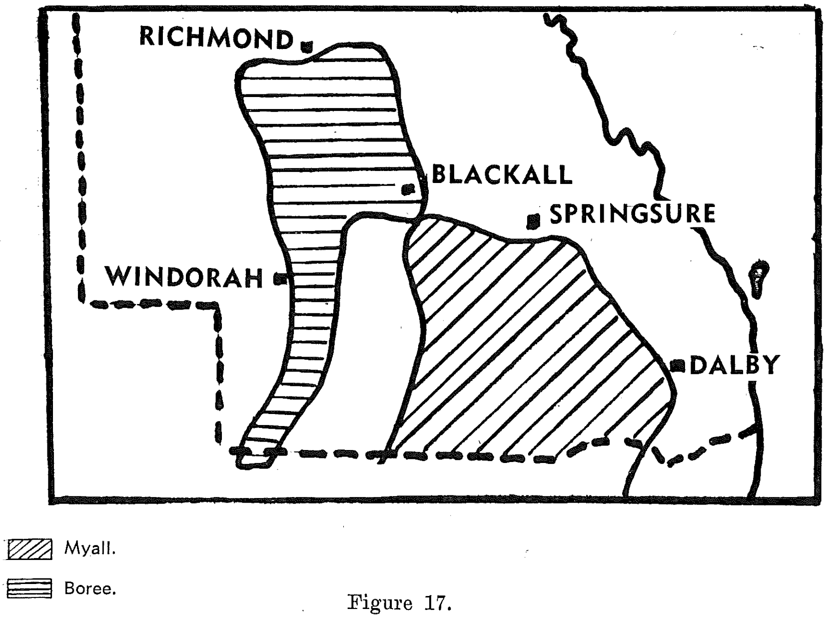


Figure 17.
Map showing the distribution of myall (*Acacia pendula*) and boree (*A. cana*).

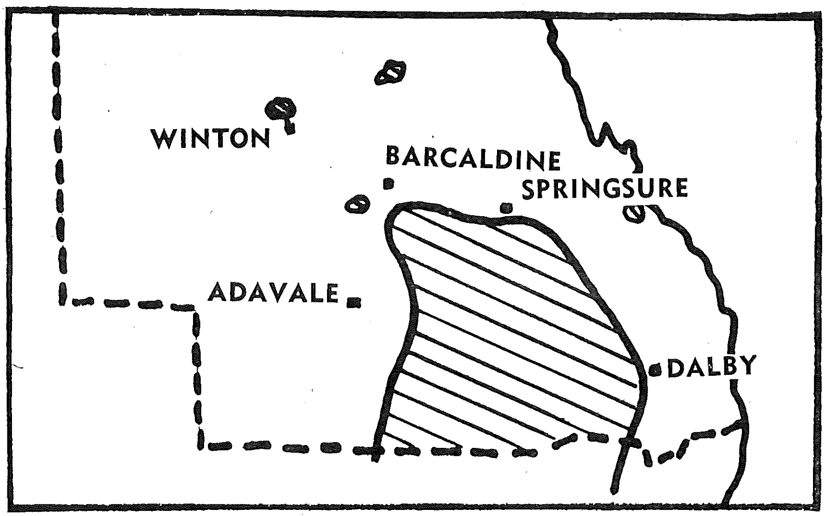


Figure 18.
Map showing the distribution of limebush (*Eremocitrus glauca*).

Seasonal distribution of rainfall obviously controls plant growth during the year, and from field observations it is known that certain plants grow in particular seasons and that different years produce a characteristic pattern of herbage. Unfortunately, there are no data on the temperature required to initiate or inhibit growth in any of the plant species native to the area under consideration, but it has been stated frequently by pastoralists in the Roma district that there the plants respond poorly to winter rains. In view of the suggestions of Klages (1942) and Forster (1941) this may be explained by the closed area shown on Figure 1, in which the average minimum winter temperatures fall below 40°F. This is probably low enough to restrict the growth of most plants.

Besides its effect on the natural flora of semi-arid Queensland, climate also appears to influence the spread of the fauna. The zero line on the P/E difference map (Figure 9) is approximately as far north as rabbits have spread, and it appears that they are unlikely to invade those regions where no reliable winter rains occur, despite the occurrence of soil suitable for their burrows.

These observations focus attention on the significance of the zero line on the P/E difference maps.

Animal Husbandry in Relation to Climatic Factors Studied.

A review of the pastoral industry in Queensland shows that sheep-raising is carried out in the climatic zones $\frac{\mathrm{Dd}}{66}$, $\frac{\mathrm{Dc}}{66}$, $\frac{\mathrm{Cd}}{66}$, $\frac{\mathrm{Cc}}{66}$, $\frac{\mathrm{Bd}}{66}$, $\frac{\mathrm{Bc}}{66}$, and $\frac{\mathrm{Bb}}{66}$. Except for the Boulia district, the eastern boundaries of the zone $\frac{\mathrm{Dd}}{66}$ represent the western boundary to which sheep-grazing has extended. The presence of sheep in the Boulia area is of considerable interest, as their maintenance is largely dependent upon the channel associations of the braided courses of the Burke and Hamilton Rivers. In the south-west the Bulloo and Paroo Rivers play a similar, though not so important, role to the northern streams. Studies in climatology such as those described in this paper cannot take account of the effects in certain areas of what are virtually immense natural irrigation systems. It is also well known that topography, particularly the occurrence of mountain ranges, influences sheep distribution.

The northern and eastern boundaries of sheep-raising are not so clearly marked. Figures 11 and 19 indicate that sheep do not extend into the north-western part of zone $\frac{\mathrm{Cd}}{66}$ nor into the northern, north-eastern and eastern part of zone $\frac{\mathrm{Bd}}{66}$. The sheep which are depastured in zone $\frac{\mathrm{Bc}}{66}$ are confined to the Clermont-Emerald-Springsure area and south of an east-west line running about 60 miles north of Roma. This line extends eastward into zone $\frac{\mathrm{Bb}}{66}$. The eastern margin of the zone $\frac{\mathrm{Bb}}{66}$ approximates the eastern boundary of sheep-raising under pastoral conditions, except for the Stanthorpe area, where the topography and soil type render large areas unsuitable for agriculture.

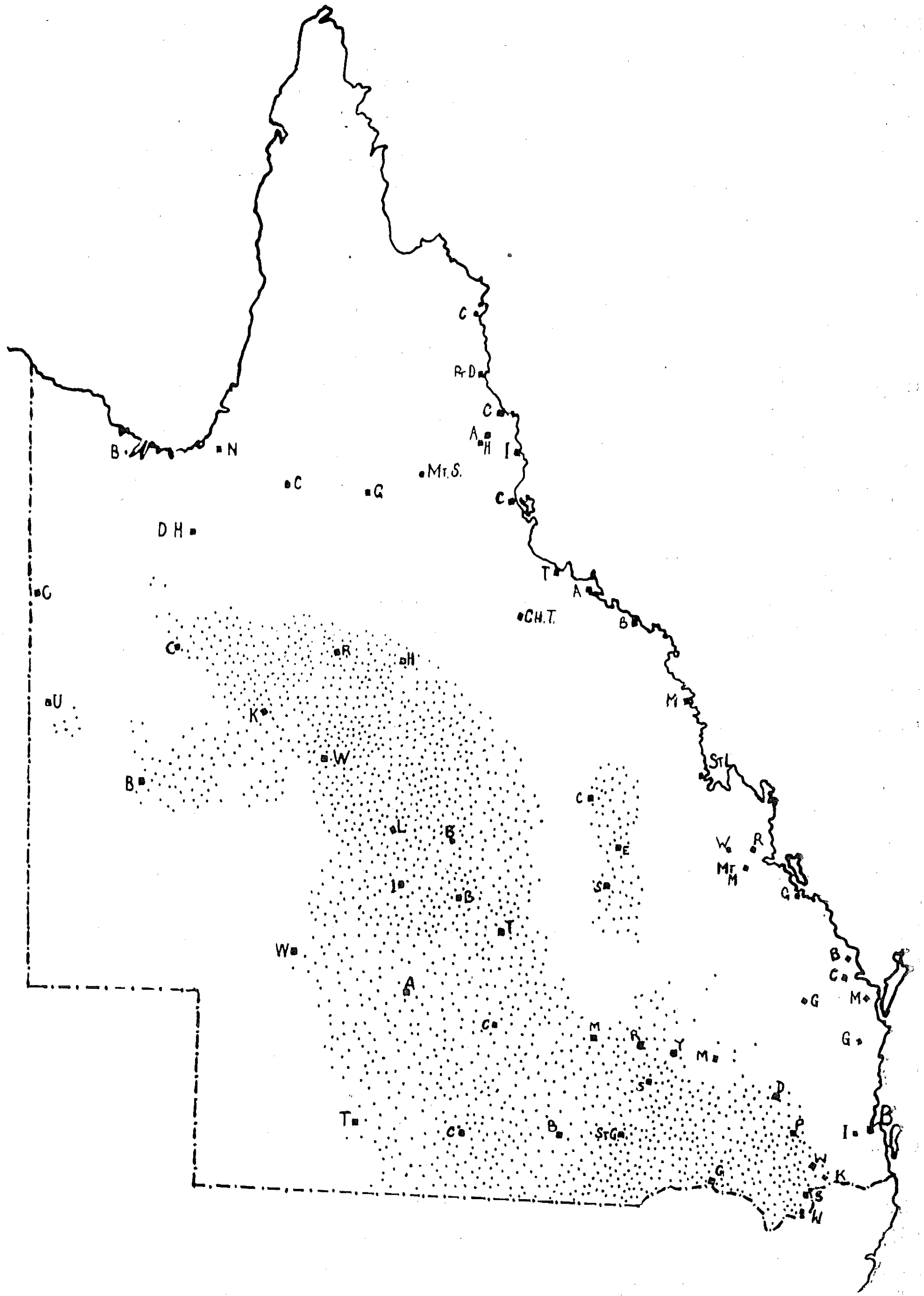


Figure 19.

Map showing the distribution of sheep in Queensland. Each dot represents 10,000 sheep. The figures are calculated on a mean maximum sheep population of a little over 20 million.

A detailed examination of the methods of sheep husbandry practised reveals some degree of stratification within the industry. Certain districts are used for the running of dry sheep while others are utilized essentially as breeding areas. Several factors have been of importance in influencing the way in which the various districts are being utilized. They may be enumerated as follows:—

(1) Climatic factors, which include total rainfall, its distribution and reliability, and extremes of temperature.

(2) Pasture types, which include type and extent of vegetation and the occurrence of poisonous plants or of "seed" or burrs likely to be harmful to wool.

(3) Topography of the country, which influences the ease with which dog-proof fences can be erected and water facilities arranged.

Obviously climate has an indirect influence on pasture types and soil formation. The components of climate, in conjunction with pasture and soil types, control the plane of nutrition of the sheep. This is probably the most important single factor to consider in sheep husbandry, as it influences wool production as well as lambing percentages.

A survey of the Queensland clip shows the occurrence of several different wool types, which are produced largely as the result of environmental differences and their effect on the plane of nutrition. While it is considered that these might be studied more fully, it is worth recording that there is a line of demarcation between different zones, classified on wool type, which follows fairly closely along the zero line of the P/E difference maps.

Average lambing percentages recorded for the whole of Queensland have never been spectacularly high. Dissection on a district basis, however, shows that there are wide variations between seasons and from district to district. Generally speaking, lambing percentages, judged on lambs marked to ewes joined, are poorer in the north-west, and are particularly bad in the Richmond-Winton-Kynuna area.

Several factors are probably of importance in influencing the low reproductive rate of Merino sheep in Queensland, which incidentally has a considerable influence on the efficiency with which wool is produced.

In the north-west the low reliability of the summer rains and the non-existence of any reliable winter rains make is desirable to join the rams only after the summer rains have fallen. This means mating at a time when the majority of rams have been subjected to a prolonged deficiency of both vitamin A and protein, and when the temperatures have been high enough to render the rams comparatively infertile. Accordingly, though the majority of ewes may have come on heat during the mating period, the chances of conception would have been low. At the same time those ewes which did conceive would be lambing on a falling plane of nutrition and at a time when surface water was failing. These conditions are not optimum for the survival of young lambs or their mothers. On the other hand, mating in expectation of summer rains to give the ewes a high plane of nutrition during the terminal stages of their pregnancy means gambling on the occurrence of rains known to be unreliable and joining at a time when the majority of ewes are not likely to experience oestrus.

A detailed study of the effects of heat on baby lambs has not been undertaken. From field observations it is clear that the chances of survival are slender for lambs dropped during mid-summer, when conditions are hot and water and feed are so scarce as to necessitate the ewes travelling long distances in an area where shade trees are virtually non-existent. There is no doubt that pregnancy toxaemia causes heavy losses of pregnant ewes subjected to such conditions. There is also evidence to suggest that weak ewes are more likely to suffer from dystokia.

The closed pocket in the Winton-Richmond-Kynuna area (Figure 2), in which six months of each year have a mean maximum temperature of over 95°F., is within the zone $\frac{\text{Cd}}{66}$ and these factors make it particularly difficult to achieve continued success in the breeding of sheep. A study of this map shows that an area which has five months with a mean maximum monthly temperature of over 95°F. includes Boulia, Urandangie and Donor's Hill, and extends between Richmond and Hughenden and between Longreach and Winton. High lambing percentages are not recorded consistently from the districts enclosed within this line. The close proximity of the 5-, 4-, and 3-month isolines near Longreach indicates some improvement in conditions for lambing to the east of that centre. Consideration of the area to the south of the zero line in the P/E difference map (Figure 9) reveals the better lambing country in Queensland. With the equitable distribution of rainfall and moderate temperatures, this area is in a more favoured position.

On the other hand, in some of these districts, particularly those included in zones $\frac{\text{Bd}}{66}$ and $\frac{\text{Bc}}{66}$ whose vegetation is of the type found mainly in or on open forest grazing country, and the broad transitional strip between $\frac{\text{Cc}}{66}$ and $\frac{\text{Bc}}{66}$, into which vegetation of this type extends, the rate of replacement of ewes from natural increase is insufficient to meet the normal losses. In the Clermont, Emerald and Springsure districts, which are located in zone $\frac{\text{Bc}}{66}$, a similar position exists. In these districts the losses as the result of worm infestation are considerably higher than those in the more arid areas of zone $\frac{\text{Dc}}{66}$, $\frac{\text{Cd}}{66}$, and the pastures do not ensure a uniformly high plane of nutrition for the sheep.

The effect of climate on the distribution and seasonal incidence of worms has been studied by Gordon (1947), who has extended his observations to include Queensland. It has been established clearly that amount and distribution of rainfall as well as temperature influence the species, extent and seasonal occurrence of parasitic worms affecting sheep. It is also established that young sheep are more susceptible than older animals and losses are heavier and more frequent in the younger age group. The heavier loss in this group is sufficient to have an adverse effect on the rate at which the breeding portion of the flocks is likely to be replaced.

No attempt has been made to study drought, though it is considered that the methods employed in this work may be applicable to this problem.

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