CLIMATIC INDICES IN THE STUDY OF DROUGHT

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The word drought is used to describe periods when crops fail or pastures die primarily because of dearth of moisture. The moisture requirements of different crops and pastures vary so widely that, unless the term be confined to those periods when there is no rain at all, there can be no universal definition of drought in terms of rainfall, temperature or evaporation. Conditions which would be considered a drought in one district would constitute a reasonably good season in another. Even at one place, criteria will vary with land utilization and drought must be considered as a deviation from a norm. Lack of rain is not the only factor which can induce drought. Sometimes, when rainfall has been sufficient for normal production, other factors may drastically reduce soil moisture or damage vegetation and thus precipitate the onset of drought conditions. These factors include fire at a critical time, improper preparation of cultivated land, excess grazing pressure, light rain on dry grass and even failure to remove excess vegetation at a critical period. A drought so induced is just as real to the farmer or grazier as one brought about by lack of rain.

Criteria for Drought

In seeking criteria for drought, it is necessary to know:-

1. the normal precipitation and evaporation pattern of the region;

2. the minimum requirements for moisture of the particular pasture or crop under consideration;

3. the effect of rainfall, temperature and evapo-transpiration on moisture in the soil.

1. Norm. It is common knowledge that arithmetical averages of elements such as precipitation do not necessarily represent the true norm. This is particularly true of rainfall in the arid and semi-arid regions. Although there is a finite lower limit to the amount of rain which can be received, there is no such upper limit and so the occasional year with abnormally high rainfall lifts the arithmetical average above the real norm. The lower the average rainfall the more marked is this deviation. The mode of the frequency curve seems to be nearer to the true norm than the arithmetical average.

2. Minimum Requirements: Many attempts have been made to determine the minimum requirements for effective rainfall. Most of them are based on the ratio of precipitation to evaporation or to saturation deficit. In order to interpret them it is necessary to know something of the vegetation of the region and of the pattern of land use. Precipitation sufficient to germinate native winter-growing herbs may be quite inadequate to initiate growth in perennial grasses or in crop plants. Rainfall sufficient to promote growth of pasture plants in one district may be insufficient to induce any response in another. It is necessary to know something of the composition of the pasture and the growth rhythm of its components before we can assess the effects of rainfall at different times of the year. Rain in certain quantity at certain times can even destroy existing pasture and induce drought conditions where none would have existed if it had not rained at all. This occurs not infrequently in the open grassland of north-western Queensland. A pasture consisting mainly of Flinders grasses will maintain sheep and cattle for months provided it remains dry but 25 points of rain in winter can turn a reasonably good season into a drought almost overnight.

3. Effect of Rainfall on Soil Moisture: In most communities rain is of little value to plants unless the water reaches the root zone. It is not rain that the plants utilize, it is soil moisture. We ought then to consider rainfall figures in terms of their influence on soil moisture. The influence will vary from soil to soil and will be greatly modified by rainfall intensity, other weather conditions, vegetation, topography and the previous history of rainfall in the area. Because of these other variables, interpretation of climatic data in terms of soil moisture is not easy. One difficulty is the dearth of measurements of moisture fluctuations in undisturbed soil.

Bath and Fox (unpublished paper) have formulated expressions for converting rainfall into depths of penetration of moisture in different soils in south-western Queensland. They also devised formulae to calculate the rate of water loss from these soils. By this means it should be possible to interpret rainfall figures in terms of fluctuations of soil moisture and to calculate the period during which certain falls of rain will remain effective in certain soils in particular districts. Following the concept of White (1951) they used different values for Initial Effective Rainfall and Carry-over Rainfall.

Thornthwaite's (1948) expression for potential evapo-transpiration is based on temperature and latitude. By comparing actual rainfall with potential evapo-transpiration and making allowance for ground storage he arrived at a Moisture Index $I_m = \frac{100s = 60d}{n}$ where s is water surplus. d is water deficiency and n is water need or potential evapo-transpiration. Dyne (1949) applied Thornthwaite's formulae to 90 stations in Queensland and produced a map showing climatic zones on this system. The zones so limited are approximately parallel to the annual average isohyets. They do not show the differences between north and south which are reflected in the vegetation of the semi-arid regions and which are important in studying drought in this region. So far as I know, no attempt has been made to apply Thornthwaite's formulae to a study of drought in Australia.

Application of P/E Formulae to the Study of Drought

One of the major difficulties in considering climatic data is the time factor, the actual sequence of events. Falls of rain are not isolated events. The effectiveness of an individual fall of rain is influenced not only by its amount and intensity but by the weather that preceded it and the weather that comes afterward. Elements such as temperature, wind velocity, cloudiness and humidity can play a critical part in determining whether a particular fall of rain shall be effective in promoting or maintaining plant growth. For this reason, the ideal way to study climatic data is in the shortest possible units of time. As units of time are increased in length and averages or summations are used the effect of sequence becomes more and more masked. Unfortunately, the shorter the time intervals being used the greater the mass of data which must be studied and it becomes necessary to use these longer units of time in order to cover an area of reasonable size. Although it is recognized that they have serious limitations most studies of drought have been based on monthly averages.

This basis was used by Moule and myself (1952) in collaboration with Miss Baynes and Miss Coussins but the figures were weighted by considering daily rainfall records. The basis of this study was the ratio of precipitation to evaporation. Evaporation was calculated from Davidson's formulae $E = K \times s.d.$ where E is evaporation in inches, s.d. is saturation deficit and K is a constant. Values for K were varied according to geographical position from 16 in the far inland to 20 in the eastern Darling Downs. Minimum monthly requirements for effective rainfall were assumed to be P/E values of 0.3 for the months of May, June, July, August, 0.25 for September, October, March, April and 0.2 for November, December, January and February.

For every station, the recorded rainfall in each month of each year was compared with the estimated effective rainfall for that month and classified as being effective or not. This data was plotted on diagrams which showed the distribution of effective rainfall throughout the year for each individual year of record. The diagrams were used to study the length of the growing seasons and the times of year when these occurred. It should be borne in mind that this study was intended to apply only to native pasture used for sheep grazing. Our definition of a growing season would not necessarily be applicable to other plants not native to the region. From these diagrams, too, it was possible to construct tables showing frequency of occurrence of droughts of different duration, their months of onset and months of termination.

The same figures were used to study rainfall on a yearly basis, using the period from 1st October to 30th September as a year so as to avoid splitting one growing season into two years. For every station, each year was assessed as being GOOD TO FAIR, MODERATE or BAD for sheep-raising or as having received NO EFFECTIVE RAINFALL. Standards for these categories were varied from station to station according to its annual rainfall, its geographical position and the behaviour of pastures and animals in that district. The standards were based on personnal experience of the response of pasture and sheep to different conditions.

Individual years were classified by estimating the number of months in each year when pasture growth <u>could</u> have taken place. Because of other factors this does not necessarily mean that pasture growth actually <u>did</u> take place. The estimate was arrived at by comparing the actual rainfall for each month with the minimum effective rainfall.

If the recorded rainfall equalled or exceeded this theoretical minimum, one point was allotted. This primary score of points was modified by considerations of the actual rainfall record. If this greatly exceeded the minimum effective figure, it was assumed to have some carry-over effect, the duration of which was assessed arbitrarily according to the amount received, the rainfall in previous months, the locality, the time of year and the subsequent rainfall. For every month in which it was estimated the carry-over effect would operate, another point was added. The final score was referred to the standards and the year classified accordingly. The classifications were plotted on a diagram to give an overall picture of the distribution in space and time of droughts in Queensland.

This method is one way of attempting to take into consideration the effect of the time factor. The objection will be made that this is a subjective approach, one not capable of mathematical confirmation. So it is, but until we can correlate precisely rainfall and other weather data with soil moisture and the response of plants, there must always be a subjective element in interpreting climatic data. Unless the climatologist is to fall into pitfalls be must know something of the soils and vegetation and land use pattern of the region he is studying.

B y applying to other districts methods similar to those used by Bath and Fox it should be possible to arrive at some such correlation but more data is needed on the penetration of rain into different soils in different districts and the rate at which this moisture is removed by evapo-transpiration. Because of the importance of transpiring vegetation in removing water from the soil it will always be necessary to know something of the vegetation cover and this varies so greatly from district to district, from season to season, and from paddock to paddock that the answer can never be more than an approximation to reality.

Causes of Drought

The methods briefly considered above are intensive studies of comparatively small areas. They could be termed local studies of drought. Tannehill (1947) studied drought in the United States on a national scale. He considered drought years to be those when the mean rainfall for the whole of the United States of America fell below the average. He showed that the deficit in the national mean rainfall in years of major droughts was not large and that quite small deficits were indicative of drought on a national scale.

He correlated these years of subnormal rainfall with pressure changes at key stations, changes in the sea temperature of the eastern Pacific Ocean and put forward hypotheses to explain how these influenced air mass trajectories and the rainfall over almost the whole of the North American continent, despite the fact that the Rocky Mountains form a high barrier on the western side of the continent.

I believe it might be profitable to apply Tannehill's methods to the study of drought on an Australia-wide basis, and to find out whether any such correlation as he suggests can be established for a continent without the complicating factor of a high range of mountains along its western seaboard. If such a correlation could be established, it might be possible to predict, by measuring sea temperatures in the Indian Ocean and barometric pressure at key stations, whether a season would be below or above average in rainfall in particular areas. If this could be done, its value to Australia would be incalculable.

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