# THE ESTIMATION AND OCCURRENCE OF AGRICULTURAL DROUGHT

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ABSTRACT

Agricultural drought is defined as existing when the soil moisture in the root zone is at wilting point or below. The occurrence and distribution of agricultural drought was determined for 41 seasons in Mid Canterbury by calculating the day-by-day changes in soil moisture. This calculation was based on a Thornthwaite estimate of daily evapotranspiration modified to allow for the effect of decreasing soil moisture, and programmed for an Elliot 503 computer.

The average number of days of agricultural drought per season was 40, varying from none to 88. Approximately two-thirds of all drought days occurred during the summer months. The distribution of the longest drought in each season conforms to extreme-value theory; this showed that very severe periods of drought of 30 days or more could be expected once every 5 years.

Highly significant correlations were obtained between seasonal non-irrigated pasture production and the number of days of agricultural drought.

## INTRODUCTION

The conventional meteorological description of drought as the absence of rainfall is of particular importance to those concerned with water supply. From the point of view of agricultural production, however, the absence of rainfall itself is not of such paramount importance unless it results in a shortage of moisture in the soil. No matter how long — and how welcome — a period of little or no rain may be in Canterbury during the winter, it does not constitute a drought to the farmer or to the home-gardener. They normally reserve this term for a period during which there is a severe and prolonged shortage of available moisture during the growing season.

## DEFINITION

The term 'agricultural drought' as used by Van Bavel was defined by him as:

" . . . a 24-hour period (starting at the time of the day at which the precipitation of the previous day is recorded) in which

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the soil-moisture stress (moisture tension plus osmotic pressure) exceeds a limit which, on basis of experimental evidence, may be taken as a point at which the productive processes of the crop are being appreciably decreased." (Van Bavel, 1953).

In a later publication, agricultural drought was redefined as: " . . . a condition in which there is insufficient soil moisture available to a crop." (Van Bavel and Verlinden, 1956).

For the present study, the following definition has been adopted:

"Agricultural drought exists when the soil moisture in the root zone is at wilting point or below."

The application of this definition to any particular area requires some knowledge of the physical properties of the soil and the rooting depth of the crop.

## DETERMINATION

Gravimetric soil-moisture determinations (carried out three times a week during the growing season) have been made under pasture at Winchmore for the last 16 years. These records provide a reasonably accurate measure of the occurrence of days of agricultural drought, although the period covered is not long enough to enable any long-term conclusions to be drawn.

The alternative is to make use of one of the methods of estimating changes in soil moisture from climatological data. Although many different methods have been used to study the occurrence and distribution of agricultural drought, the Thornthwaite approach was used in the present study mainly because it has proved to be satisfactory for the area (Fitzgerald and Rickard, 1960) and also because of its simplicity.

In earlier work at Winchmore (Rickard, 1960) all calculations of daily changes in soil moisture were made by hand, and potential evapotranspiration values were used from field capacity to wilting point. In the present study the calculations have been carried out on an Elliot 503 computer. The main points are as follows:

(1) Daily evapotranspiration was calculated each day from the maximum and minimum screen temperatures.

(2) A relatively simple modification to allow for the effect of increasing soil-moisture tension on the evapotranspiration rate was introduced. This modification was a straight-line reduction of the daily potential evapotranspiration from 100% to 0%, and could be introduced and terminated at any chosen deficit.

(3) The program printed out the daily change in deficit, the number of days at or below wilting point in each month, and the cumulative total through the season September to May.

From an examination of measured rates of drying of soil beneath pasture, and knowledge of the extent to which the Lismore soil could dry out below wilting point, a number of possible modifications were arrived at and tested. The number of days of actual agricultural drought obtained from the 16 years of gravimetric determinations was used as the standard against which the drought days obtained from the various modifications were compared. The modification used was as follows: over the range from zero deficit to a deficit of 1.30 in. the actual evapotranspiration was equal to the potential evapotranspiration; from a deficit of 1.30 in. to 2.50 in. the potential evapotranspiration was reduced as shown in Fig. 1. Further testing of this modification by graphing the day-by-day changes in calculated soil-moisture deficit together with the measured changes in soil moisture gave excellent agreement.

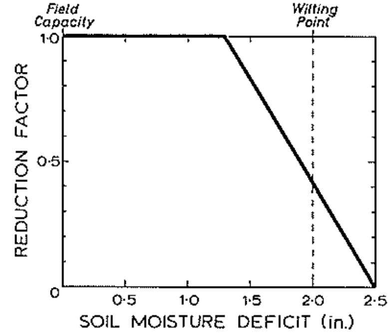


FIG. 1 — Modification of potential evapotranspiration with increasing deficit.

## RESULTS

Climatic data were obtainable for the seasons 1927–8 to 1951–2 from the meteorological station at Ashburton, and from 1962–3 to 1967–8 from the station at Winchmore. The period 1 September to 31 May was covered in each season. In examining the results, it was assumed that where two periods of agricultural drought were separated by only one day the periods could be combined. This assumption increased the total number of drought days over the 41 seasons by 12.

From 1927–8 to 1967–8 there were 1,628 days of agricultural drought, averaging 40 per season and ranging from none to 88. This agrees reasonably well with an average of 42 days with a range from 2 to 96 obtained over the 16 seasons for which actual soil-moisture records were available. A summary of the seasonal distribution of drought days is given in Table 1 and the average monthly distribution in Table 2.

TABLE 1 — Seasonal distribution of drought days.

| *No. per season* | *No. of seasons* |
|---|---|
| 0–20 | 11 |
| 21–40 | 12 |
| 41–60 | 6 |
| 61–80 | 10 |
| >80 | 2 |
| | 41 |

TABLE 2 — Average monthly distribution of drought days.

| *Month* | *Average number* | *Percentage* | |
|---|---|---|---|
| Sep | 0 | 0 | Spring: 7.6 |
| Oct | 0.3 | 0.7 | |
| Nov | 2.8 | 6.9 | |
| Dec | 5.3 | 13.4 | Summer: 64.8 |
| Jan | 10.4 | 26.3 | |
| Feb | 10.1 | 25.1 | |
| Mar | 6.1 | 15.3 | Autumn: 27.6 |
| Apr | 4.4 | 11.1 | |
| May | 0.5 | 1.2 | |
| | 39.8 | 100.0 | |

Approximately two-thirds of all drought days occur during the summer; drought during the autumn is almost four times as likely as it is in the spring. In decreasing order of dryness, the months of the growing season are: January, February, March, December, April, November, May, October, September.

Although the total number of drought days per season is a valuable climatic parameter, the duration of individual periods of drought is of interest. During the 41 seasons, the longest period of consecutive drought was 1932–33, from 14 February to 23 April — 69 days. (This period did not include any single 'non-drought' days).

Other periods of more than 30 consecutive days of drought are included in Table 3.

TABLE 3 — Long periods of agricultural drought.

| *Number of days* | *Dates* |
|---|---|
| 69 | 14. 2.33–23. 4.33 |
| 52 | 19. 1.64–10. 3.64 |
| 39 | 11. 1.32–18. 2.32 |
| 34 | 23. 1.28–25. 2.28 |
| 33 | 29.12.58–30. 1.59 |
| 32 | 27.10.61–27 11.61 |

The last period listed in Table 3 was the only occasion during the 41 years that a substantial drought occurred in the spring.

A frequency table of length of drought periods was compiled, and this did not appear to fit any statistical distribution. A Markov-chain model was also used but the fit, tested by the chi-squared method, was bad. Table 4 gives drought frequency in weekly intervals.

TABLE 4 — Frequency of seasonal drought

| *Weeks* | *Frequency* | *Cumulative percentage* |
|---|---|---|
| 0– 1 | 93 | 57.1 |
| 1– 2 | 26 | 73.0 |
| 2– 3 | 23 | 87.1 |
| 3– 4 | 13 | 95.1 |
| 4– 5 | 5 | 98.2 |
| 5– 6 | 1 | 98.8 |
| 6– 7 | 0 | 98.8 |
| 7– 8 | 1 | 99.4 |
| 8– 9 | 0 | 99.4 |
| 9–10 | 1 | 100.0 |

It can be seen that more than half the droughts occur in periods of a week or less.

## EXTREME ANNUAL DROUGHTS

Although the distribution of drought days could not be used for making estimates of the likely length of droughts it was felt that the distribution of the largest drought in each year would conform to extreme-value theory (Gumbel, 1958). A graph of the data on Gumbel probability paper showed good agreement and the distribution was fitted by the least-squares method. This showed that extreme annual droughts could be expected to be 45 days or more every 20 years and 18 days or more every two years. Other values are given in Table 5.

TABLE 5 — Extreme annual droughts.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| *Extreme annual drought (days)* | : | 5 | 10 | 20 | 30 | 40 | 50 |
| *Return period (years)* | : | 1.1 | 1.3 | 2.3 | 5 | 12.5 | 31 |

## EFFECT OF DROUGHT ON PRODUCTION

Even brief periods of drought can decrease agricultural production significantly, and prolonged periods can have a severe effect. Pasture production data from long-term field experiments at Winchmore were used to give quantitative expression to this effect. Annual non-irrigated pasture production for a period of 11 seasons together with the total number of days of agricultural drought in each season were used to calculate the following regression equation:

$$P = 6884 - 43.0D \qquad r = -0.82^{**}$$

The production data used in this equation were obtained from an experiment sampled at approximately 28-day intervals; similar data were available from an area sampled at 14-day intervals.

$$P = 6139 - 35.9D \qquad r = -0.94^{**}$$

In both equations, $P$ is the annual production in pounds of dry matter per acre, and $D$ is the number of days of agricultural drought.

In an average season of 40 drought days, pasture production is approximately 25 percent less than in a season without drought. It should be kept in mind that the number of days of agricultural drought is a relatively severe measure of dryness, and that pasture production will be adversely affected before wilting point is reached.

## CONCLUSIONS

The occurrence and distribution of periods of agricultural drought can be estimated from past meteorological data by the use of a modified Thornthwaite evapotranspiration estimate. If sufficiently long-term records are available, an assessment of the probable occurrence and duration of agricultural drought in the future is possible. The close correlation between the number of days of agricultural drought during a season and the non-irrigated production for that season means that an estimate of probable future fluctuations in annual pasture production can be obtained.

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