# A NEW METHOD OF ANALYSIS FOR HAY DRYING WEATHER

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A numerical method was devised for the statistical analysis of hay drying weather. The output from this method could help farm planners optimize the use of machinery in hay harvesting operations. The method depends upon the continuous integration of drying and rewetting potentials over the whole field drying period. A data-base, representing lengths of drying periods in days required to dry hay to a given moisture content, was generated from historical weather records and used for probability analysis. The probability of a specific length of hay drying on a chosen date was obtained by counting the occurrence of that length of drying period over all years of record. The main advantage of this approach over previous methods is that it bypasses the need to assume that a fixed sequence of days is required to dry hay. Also, the approach allows information to be obtained concerning the levels of certainty or risk of getting different numbers of cutting days, followed by acceptable lengths of drying period. The level of certainty associated with haying operations due to weather provides a means of quantifying the year to year variability and thus could be an important factor in farm planning.

## INTRODUCTION

The importance of weather probabilities in the timeliness of farming operations has long been recognized in farm planning. Timeliness is a measure of the ability to perform an operation at the time that optimizes production (Hahn 1971). Timeliness constraints also explicitly define the required level of investment in farm machinery for any given type and size of operation. In long-term investment, the ability to schedule the time available between certain dates is crucial in deciding the machine size requirements (Hunt 1972). However, timeliness or scheduling in most farm operations depends on weather events. Thus weather probabilities such as haying weather weigh heavily in agricultural planning.

This paper describes a new method of analysis for hay drying weather from a long-term planning point of view. The goal of the analysis was to produce probability estimates of hay making risks in a form which is usable in farm machinery selection and other farm planning models (Batterham et al. 1973; Stonehouse 1971). The emphasis is on the methods of presentation and the rationale behind them. Haying weather presents a more complex problem than tillage workday weather (Brown and Van Die 1974; Selirio and Brown 1972) because once hay is cut, all weather events over the next few days must be endured until the hay becomes dry enough to harvest and store. Hence haying weather requires not only a different method of analysis but also a different method of data presentation.

Previous methods of analysis for haying weather rely heavily on rainfall patterns. In a publication on hay making probabilities for Missouri, Borgman and Brooker (1961) used sequences of 2 or 3 rainfree days as criteria for haying weather. A similar approach was used by D.M. Brown and I.S. Selirio (personal communication) in generating haying weather probabilities for two sites in Ontario (Moore 1971). A hay drying day was also defined by Hayhoe and Jackson (1974) as having a certain drying potential as well as being relatively rainfree. However, these previous models were not adequate for analyzing hay drying weather for three reasons: (1) the sequences for hay drying periods often involve more than 3 or 4 days for which conditional probabilities become very cumbersome, (2) each day can be evaluated only as either an acceptable or unacceptable hay drying day, which may lead to a significant accumulated error in longer periods and (3) having evaluated the probabilities for sequences of drying days in a given time frame, it is difficult to relate them to the number of possible cutting days during that time. Although the inclusion of drying potential in the definition of hay drying by Hayhoe and Jackson (1974) is an improvement over methods using rainfall only, it still does not alleviate the problems mentioned above. An alternate method of analysis was therefore needed for haying weather.

## PROCEDURES

The data-base from which the probabilities were derived consisted of a matrix of integers. This matrix was defined by the years studied (rows) and days considered to be haying season (columns). The matrix was developed by following these basic steps: (1) The potentials for drying and rewetting of hay swaths were simulated using a field hay drying model called FHAYD (Dyer and Brown 1977a). FHAYD requires as inputs daily values of precipitation, minimum and maximum temperatures and hours of bright sunshine. (2) The drying period was evaluated by the time required (number of days after cutting) for hay to become suitably dry for harvesting. Various initial and final moisture contents can be assumed in FHAYD depending on the dryness of hay at cutting and the method of harvest. In this paper, the initial and final moisture contents (wet weight basis) used, were 80 and 23% for dry hay and 80 and 55% for haylage. (3) This method of evaluating hay drying periods was then applied to climatic records by assuming that each date of the haying season was a cutting day and the first day of a drying period. (4) An integer representing the length of the drying period in days which would follow if hay were cut on that date was assigned to each date of the year. Since the simulation was based on daily weather records, the predicted drying period was precise only to within 1 day. (5) A matrix for dry hay and another for haylage were produced for all years that climatic records were available and stored for further analysis.

Each drying day matrix contained integers between 0 and the longest drying period simulated in days. Since each date was ranked as a possible cutting day, the integers already represent periods of days needed to dry hay from that date; hence there is no need for the sequential occurrence of these integers to be known. Counting the occurrence of integers over all years analyzed gives inferred probabilities for each length of drying period. For example, the number of times that the integer 4 occurs on a given date over all years divided by the total number of years studied, gives the probability of hay being suitable for harvesting 4 days after this cutting date. The probability of having hay dry enough for harvesting no later than the end of the 4th day is derived by counting the integers 1, 2, 3 and 4.

### Table-Making Procedures

Since the goal of this study was to produce information in a form that is readily usable for farm planning, the hay drying

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**TABLE I PROBABILITY OF REACHING 23% BY THE 3RD, 4TH ... 7TH DAY AFTER CUTTING AT HARROW, ONTARIO**

| Week of | *n* drying days or less | | | | |
|---|---|---|---|---|---|
| | 3 | 4 | 5 (%) | 6 | 7 |
| 31 May - 6 June | 25 | 53 | 65 | 77 | 85 |
| 7 June - 13 June | 24 | 48 | 63 | 76 | 85 |
| 14 June - 20 June | 32 | 52 | 69 | 81 | 87 |
| 21 June - 27 June | 35 | 60 | 75 | 87 | 93 |
| 28 June - 4 July | 43 | 72 | 86 | 93 | 97 |

**TABLE II PROBABILITY OF HAVING AT LEAST 1, 2, ... 7 CUTTING DAYS PER WEEK FOR DRYING PERIODS OF ≤4 DAYS FOR DRY HAY AT HARROW, ONTARIO**

| Week of | *n* cutting days or more | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 (%) | 5 | 6 | 7 |
| 31 May - 6 June | 90 | 84 | 68 | 50 | 34 | 24 | 18 |
| 7 June - 13 June | 86 | 72 | 56 | 50 | 36 | 24 | 12 |
| 14 June - 20 June | 92 | 72 | 64 | 52 | 42 | 26 | 14 |
| 21 June - 27 June | 92 | 88 | 76 | 64 | 46 | 32 | 22 |
| 28 June - 4 July | 100 | 100 | 92 | 78 | 66 | 46 | 20 |

data were presented in various ways. All the data were averaged over each standard climatological week, a notation that divides the year into consecutive weeks starting on 1 March (Brown and Van Die 1974). The first table format gives the probability of the occurrence of drying periods of *n* days or less (Table I). These probabilities were obtained by integrating over all the probabilities for the lengths of drying periods less than or equal to *n* days. The second format gives probabilities of drying hay in *n* days or less for specific numbers of cutting days per week (Table II). A date in a week is a cutting day if cut hay will dry in *n* days or less from that date. The third table format gives the expected number of cutting days per week at several specific probability levels (Table III). The latter two table formats were patterned after the tillage workday tables published by Brown and Van Die (1974). The adaption of these tables of probabilities was made possible by treating a good drying period as an individual event instead of as a sequence of events.

## RESULTS AND DISCUSSION

The tables of hay drying weather are illustrated using 50 yr of climatological data at Harrow, Ontario. A technical bulletin on hay drying weather at four sites in Ontario, based on the techniques described in this paper, is being prepared for publication (Dyer and Brown 1977b). In the bulletin, the season from 31 May to 19 September was considered, and hence includes possible cutting dates for a two-, three-, or four-cut system per year. The first 5 wk are used here to illustrate the techniques.

Table I shows the probability of occurrence of drying periods of *n* days or less to produce dry hay. The range of drying for dry hay was considered to be from an initial moisture content of 80% (wet weight basis) to a final harvesting moisture content of 23% (wet weight basis). The value of 23% was assumed to represent the average swath moisture content at harvest time. The column corresponding to the longest drying period has the highest values because the probabilities are cumulative from left to right. For example, the probability of hay being dry by the 5th day after cutting also includes the probability of it being dry by the 1st, 2nd, 3rd and 4th day after cutting.

Table II shows the probabilities for the possible different numbers of times that one might expect to cut hay in each week. A good cutting day depends on the maximum length of time that cut hay can lie in the field before hay quality becomes unacceptable due to leaching, bleaching or mildew. A maximum drying period of 4 days was used by assuming that the criterion of a good cutting day for dry hay is one with a drying period of 4 days or less. Values in this table are accumulated from right to left; hence the expectation of having at least 5 cutting days is never as high as the expectation of having at least 3 cutting days in a week.

Table III gives the expected number of cutting days per week at specified certainty levels of 1 yr out of 2, 2 yr out of 3, 3 out of 4, 4 out of 5, and 9 out of 10 for dry hay. The expected number of cutting days at specific certainty levels was derived because the user often has in mind the level of risk on which he is willing to operate. These expected numbers of cutting days were calculated by interpolating between the columns of the probabilities for various numbers of cutting days per week given in Table II.

Table IV gives the expected number of cutting days per week at specified certainty levels of 1 yr out of 2, 2 out of 3, 3 out of 4, 4 out of 5 and 9 out of 10 for haylage. The format of this table is identical to Table III. The procedures used to calculate the number of cutting days for haylage were also identical to those for dry hay except for the final harvest moisture content of 55% (wet weight basis). Also, the criterion of a good cutting day for haylage is one with a drying period of 2 days or less.

Values presented in Tables III and IV are based on field drying time and do not include the actual harvesting time. Harvesting time depends on many other factors such as machinery capacity to harvest and transport, hay yield per unit area, and the farmer's ability and experience. Cutting day criteria can include management factors that have measurable effects on field drying time, such as windrowing or raking. The changes could be done in the original hay drying model (Dyer and Brown 1977a) if and when

**TABLE III EXPECTED NUMBER OF CUTTING DAYS PER WEEK AT CERTAINTY LEVELS 1 YR OUT OF 2, 2 OUT OF 3 ... 9 OUT OF 10 FOR DRYING PERIODS OF ≤ 4 DAYS FOR DRY HAY AT HARROW, ONTARIO**

| Week of | Certainty levels | | | | |
|---|---|---|---|---|---|
| | 1/2 | 2/3 | 3/4 (days) | 4/5 | 9/10 |
| 31 May - 6 June | 4.0 | 3.1 | 2.6 | 2.3 | 1.0 |
| 7 June - 13 June | 4.0 | 2.3 | 1.8 | 1.4 | 0.7 |
| 14 June - 20 June | 4.2 | 2.7 | 1.8 | 1.6 | 1.1 |
| 21 June - 27 June | 4.8 | 3.8 | 3.1 | 2.7 | 1.5 |
| 28 June - 4 July | 5.8 | 4.9 | 4.3 | 3.9 | 3.1 |

**TABLE IV EXPECTED NUMBER OF CUTTING DAYS PER WEEK AT CERTAINTY LEVELS 1 YR OUT OF 2, 2 OUT OF 3 ... 9 OUT OF 10 FOR DRYING PERIOD OF ≤2 DAYS FOR HAYLAGE AT HARROW, ONTARIO**

| Week of | Certainty levels | | | | |
|---|---|---|---|---|---|
| | 1/2 | 2/3 | 3/4 (days) | 4/5 | 9/10 |
| 31 May - 6 June | 5.5 | 4.9 | 4.1 | 3.3 | 2.5 |
| 7 June - 13 June | 5.1 | 3.9 | 3.3 | 2.9 | 2.3 |
| 14 June - 20 June | 5.4 | 4.7 | 4.4 | 4.2 | 3.3 |
| 21 June - 27 June | 6.1 | 5.3 | 4.9 | 4.7 | 4.2 |
| 28 June - 4 July | 6.3 | 5.6 | 5.2 | 5.0 | 4.2 |

the effects of these factors are quantified. More research is needed in order to better understand management effects on field drying of hay.

Haying weather information presented in Tables I to IV is useful in long-term planning and decision making. It is not intended to provide day to day haying weather information in any current year.

### Implications of Haying Weather Information

The methods of presenting information in this paper are useful for comparing risks of haying associated with different times of the growing season, geographical regions,

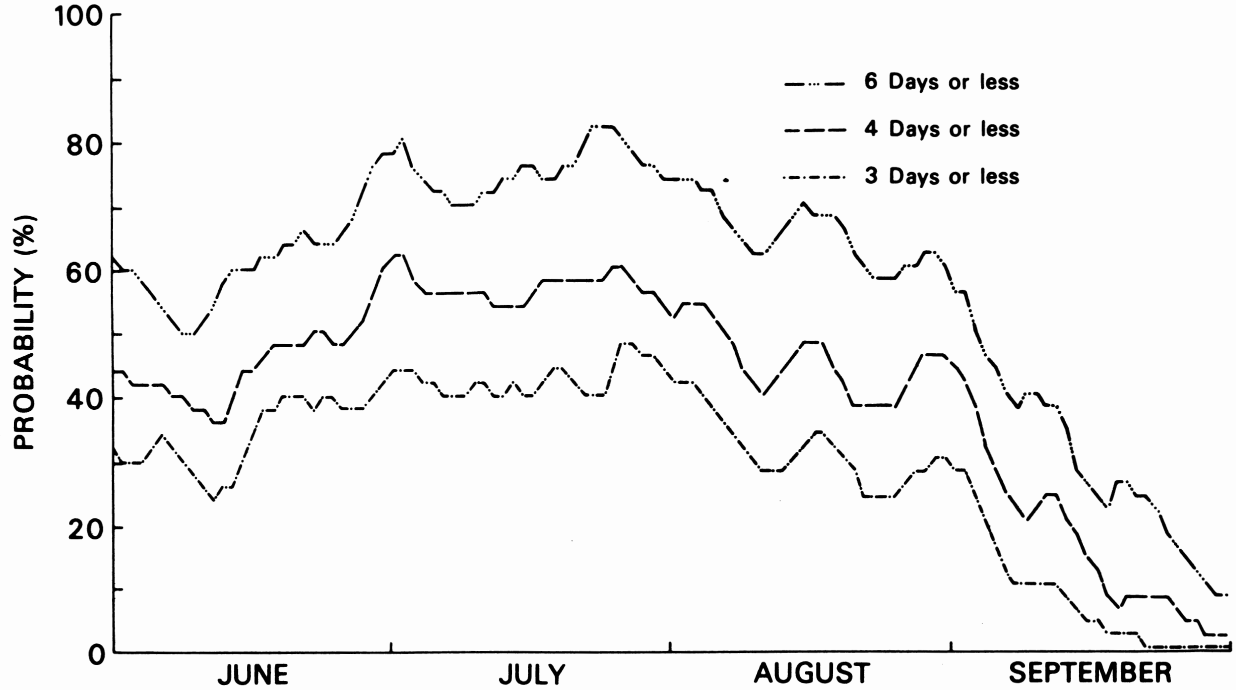


**Figure 1.** Seasonal variation of probability of drying periods of 3, 4 and 6 days or less for dry hay at Harrow, Ontario (5-day moving average).

harvesting methods and crop qualities, from which farm planners could benefit.

Comparisons of seasonal and regional haying risks could be made from results presented in tables such as Tables I and III. For example, frequency distributions can be derived from Table I to show seasonal variation of the probability of different lengths of drying periods for dry hay. This is illustrated in Fig. 1 for drying periods of 3, 4 and 6 days or less for dry hay in the Harrow area. Comparison with frequency distributions derived in a similar manner at other locations in Ontario will show regional differences of haying weather.

The haying weather information is useful also in evaluating different harvesting methods. Risks associated with dry hay and haylage, shown in Tables III and IV, respectively, are useful to farm planners in their choice of a harvesting method. Baled and loose hay are both considered as dry hay. Grass silage, another haying method, is not considered in this work, since the field drying period required is usually not long enough for weather to be a major limiting factor.

The results of the analysis are useful in showing the risks associated with the different qualities of hay and its implication on machinery investments. Based on the assumption that the quality of hay deteriorates according to the amount of time it is left lying in the field, a table similar to Table III can be prepared for a lower quality dry hay using a 6 days or less drying period instead of 4. Likewise, a table similar to Table IV can be prepared for lower quality haylage based on a 3 days or less drying period instead of 2. It is obvious that the longer drying period for lower quality hay will result in more cutting days available. This implies that if a farmer is willing to accept a lower quality hay, he will have more time available to harvest and hence need less machinery capacity compared to that required to harvest a better quality hay.

**Evaluation of the Method**

The new method described in this paper was evaluated by comparing results from Tables I to IV with haying weather data reported by Moore (1971), which were the only previously published data for the Harrow area (Table V). Moore's data were based on the assumption that sequences of 2 dry days were necessary to harvest haylage and 4 for dry hay. A dry day was defined as one having less than 2.5 mm of precipitation, provided the previous day had less than 12.7 mm of precipitation. Since Moore's data were available for the month of June only, the average number of cutting days for the same period (31 May - 27 June) were taken from Tables III and IV for dry hay and haylage, respectively, by summing the 1 yr out of 2 columns over the first four rows. The 1 yr out of 2 certainty level values are average expected number of cutting days and thus correspond to Moore's values which were defined by average probabilities during that period.

The new method described in this paper predicted more cutting days for dry hay and haylage than Moore's (Table V). The difference for dry hay can be explained partly by the large proportion of drying periods of 4 days or less which were actually drying periods of only 3 days (see Fig. 1). If Moore's criterion for dry hay were reduced to only 3 dry days, Moore's value would then equal 15 instead of 12 which agrees better with the result of the present study. This illustrates the problem of using fixed sequences of days as a criterion. The number of possible cutting days must be derived separately for 3 and 4 dry day sequences. Also, the assumption that hay drying requires a fixed number of drying days is not necessarily correct, since a variety of different length sequences is needed depending on the varying drying potential on days within those sequences. For example, the total drying potential over 3 sunny days could be the same as over 4 cloudy days. Sufficient drying also could occur in a 4-day period composed of 2

**TABLE V EXPECTED NUMBER OF CUTTING DAYS AT CERTAINTY LEVEL 1 YR OUT OF 2 FOR DRY HAY AND HAYLAGE DURING THE MONTH OF JUNE AT HARROW, ONTARIO**

| Source | Period | Haying methods: Dry hay (days) | Haying methods: Haylage (days) |
|---|---|---|---|
| Present study | 31 May - 27 June | 17 | 22 |
| Moore (1971) | 1 June - 30 June | 12 | 18 |

rainfree days followed by a day with 2.5 mm of rain and another rainfree day. In this combination of weather events, 3 or 4 dry day sequences are not attained, yet FHAYD (Dyer and Brown 1977a) would predict this as a 4-day drying period if the total drying potential were sufficient. This also is true for haylage, when a 3-day period is composed of a rainfree day, of exceptional drying potential, between 2 days with rain. FHAYD would predict this as a 2-day or less drying period for haylage even though it is not a sequence of 2 dry days. Finally, the difference in the results (Table V) could also be attributed to the acceptance of only those days with less than 12.7 mm of rain on the preceding day by Moore (1971), whereas there is no such restriction in the method used in this paper.

The new method of analysis described in this paper accounts for year to year variability by giving the number of cutting days for several different levels of certainty. For example, in 9 yr out of 10, only 3.1 cutting days can be expected for dry hay (drying period of 4 days or less) during the week of 28 June - 4 July at Harrow, whereas 5.8 cutting days can be expected in 1 yr out of 2 (see Table III). For haylage (drying period of 2 days or less), 4.2 cutting days can be expected in 9 yr out of 10 and 6.3 days in 1 yr out of 2 (see Table IV). If a farmer plans to cut hay that week and wishes to be assured success in harvesting dry hay in 9 yr out of 10, he should plan on 3 days only to cut hay and should therefore plan his machinery capacity accordingly.

## CONCLUSIONS

From the above discussion it can be concluded that the procedures proposed in this paper define explicitly the time available for hay making. The new method of analysis also allows a variety of information concerning hay drying to be obtained with ease such as the expected drying periods, or expected cutting days for a given drying period, at different levels of certainty. This type of haying weather information is useful for comparing risks of haying during different times of the year and also, for evaluating the different harvesting methods. The new method of analysis considers the influence of weather on haying operations and hence could be an important input to farm planning models that take into account timeliness in selecting machinery capacity.


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