13B.3 ANALYSIS OF WEATHER EXTREMES ASSOCIATED WITH WINTERKILL OF WINTER WHEAT

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1. INTRODUCTION

There are a number of factors that contribute to winterkill of winter wheat (*Triticum aestivum* L.) in North America (Gusta and Fowler, 1977; Gusta et al., 1982; Savdie, 1988). They include low temperatures (Aase and Siddoway, 1979; Larsen et al., 1988; Ritchie and Otter, 1984), drought, flooding, soil heaving, ice encasement (Andrews and Pomeroy, 1977; Andrews and Pomeroy, 1979; Andrews, 1996), desiccation, smothering, diseases and insects. Within a small plot, large spatial and year-to-year differences in survival can be expected (Hayhoe and Andrews, 1998). These differences can be related to topography and variation in environmental factors such as snow depth, winter rainfall and temperature extremes (Ouellet, 1977).

The winter wheat winter survival data for this study were collected during seven winters on a loam soil plot that was subject to frequent winter flooding and ice sheet formation. Previous studies on the plot have shown that low-lying areas had poorer winter survival, particularly when rainfall and winter thaws generated surplus water that subsequently froze and encased the plants in ice (Hayhoe and Andrews, 1999). The results have also shown that there were cultivar differences in tolerance of extreme weather and ice sheet formation and that significant year-to-year variation in winter survival could occur (Hayhoe and Andrew, 1998). The objective of this study was to select years with the highest winterkill and examine weather and soil conditions that were suspected of having caused it. A further objective was to assess the risk of these extreme weather conditions occurring using historical weather records from the nearby climatological station.

2. METHODS

The field plot where survival data were collected was located on the Central Experimental Farm at Ottawa, Ontario (45° 23' N, 75° 43' W) on a Grenville loam (melanic brunisol) soil. The plot was approximately 24 m by 40 m (Hayhoe and Andrews, 1999). A very gentle slope grading into a low-lying depression characterized the plot topography.

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The plot was divided into rows and ranges as described by Hayhoe and Andrews (1999). Seven years (1993-2000) of winter survival data were collected on this plot. For the first five years of the experiment, two cultivars (a soft white and a hard red winter wheat) were planted in alternating groups of four rows for a total of 52 rows for each cultivar. The row spacing was 0.23 m. For convenience, they were planted the whole 40 m length of the plot. The rows were then divided into 3 m ranges with a 1 m path between each range. The percentage of each row within each range that emerged was measured in the fall after the crop was established. The percentage of each row within each range with live plants was measured in the late spring after new growth had begun. Winter survival was estimated by taking the ratio of the percentage measured in the spring divided by the percentage emergence in the fall.

For 1998 to 2000, a different method was used to estimate emergence and survival. A 2.5 m rod with 0.1 m increments was set in the row and the number of 0.1 m gaps along the row was counted with a resolution of 0.05 m in the fall to estimate percentage emergence and in the spring to estimate the percentage of the row that survived. In 1998, the two cultivars were planted in alternating groups of seven rows for a total of 56 rows for each cultivar. The row spacing was 0.2 m. Only three of each set of seven rows were sampled for emergence and survival. Edge rows were skipped as well as rows along the tractor tire. For 1999-00, two cultivars were planted in alternating groups of four rows for a total of 56 rows for each cultivar. The row spacing was 0.23 m.

Each range was divided into four blocks for a total of forty blocks on the plot. Survival for each cultivar and year were averaged over the blocks. Each block was assigned x and y coordinates for the centre of the block based on the origin at the northwest corner (Hayhoe and Andrews, 1999). Elevation was measured in the fall of 1999 at the centre of every row where emergence and survival were measured. In the winter of 1993-94, 16 thermocouples were inserted at the 0.05-m depth in the soil at strategic locations in the plot, which were selected based on topography. In the following six years, soil temperature was measured on a grid at a depth in the soil of 0.05 m with four thermocouples evenly spaced in each range for a total of 40. Measurements were recorded hourly. In the fall, snow rulers were installed on the plot and used to monitor snow or ice accumulation.

Weather data from the Ottawa climatological station located within 500 m of the plot for the period from 1889 to 2000 were used. Daily maximum and

Table 1

Survival and soil temperature extremes at the 0.05-m depth measured on the plot

Year	Survival (%)		Minimum Soil Temperature at 0.05-m (°C)		
	Mean	SD	Median	Lower Quartile	Upper Quartile
1993-94	85.1	20.5	-8.0	-8.2	-7.8
1994-95	73.7	29.3	-9.5	-10.4	-8.2
1995-96	93.5	5.6	-3.2	-3.7	-2.3
1996-97	18.3	15.4	-8.3	-10.4	-6.6
1997-98	69.6	17.5	-2.2	-2.4	-1.9
1998-99	85.9	16.2	-6.5	-7.1	-6.0
1999-00	16.7	23.0	-17.0	-18.5	-15.6

minimum air temperature, rainfall, and snowfall were available for the period of record. Data for the depth of snow on the ground and soil temperature were not available before 1958. Soil temperatures reported in this study are based on morning observations.

3. RESULTS

In five of the seven years the mean survival rate was at least 70% (Table 1). In the remaining two years, the survival rate was less than 20%. In 1996-97, when winter survival was only 18.3%, winter flooding and ice sheet formation were felt to be the cause of winterkill (Hayhoe and Andrews, 1998). The plot was completely covered with an ice sheet during the winter and by March 3, 1997 the depth of ice ranged between approximately 0.1 and 0.2 m (Hayhoe and Andrews, 1999). In 1999-00, when survival on the plot was 16.7%, it was felt that extreme cold temperatures caused the winterkill. The results in Table 1 confirm that soil temperatures at the crown depth of the winter wheat plants, as indicated by 0.05-m soil temperature, were sufficiently cold to cause winterkill due to cold temperatures in 1999-00 (Savdie et al., 1991). The median of the lowest soil temperature at the 0.05-m depth measured on the plot in 1999-00 was -17°C with

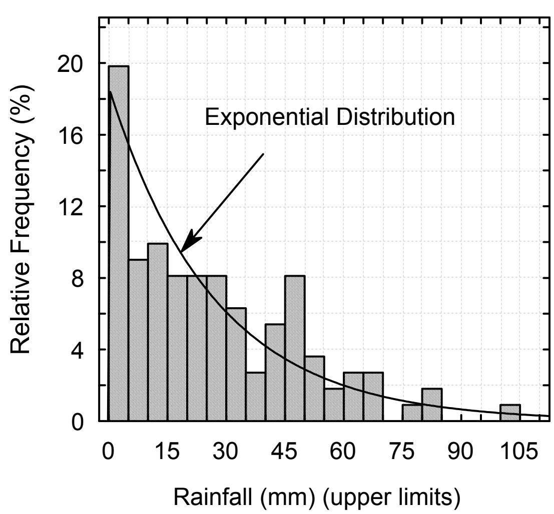

Figure 1. Frequency Distribution of the Total December Rainfall

the lower quartile equal to –18.5°C. The next lowest soil temperature measured on the plot at 0.05-m occurred in 1994-95. The median equaled –9.5°C (Table 1).

The winter of 1996-97, which had winter survival of 18.3%, was characterized by intermittent

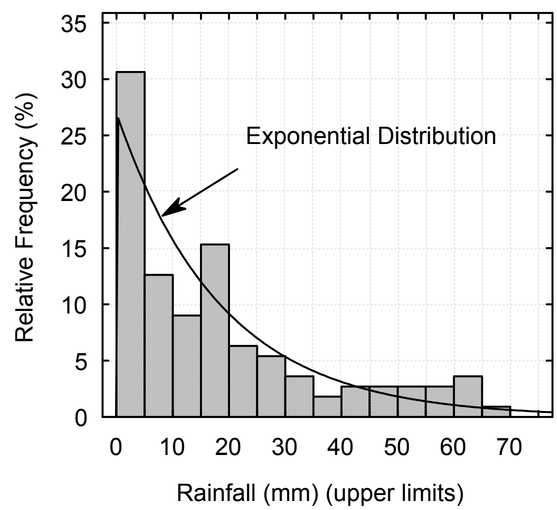

Figure 2. Frequency Distribution of the Total January Rainfall

snow cover early in the winter and record levels of winter rainfall. In December 1996 the total rainfall was 48.6 mm, which was well above the average of 26.8 mm. The frequency distribution for total December rainfall is shown in Fig. 1. Based on the 111-year record, total December rainfall was less than or equal to 50 mm 86% of the time. The rainfall during January 1997 was 23.7 mm, which was above the average of 18.5 mm. January rainfall would be expected to be less than or equal to 25 mm 74% of the time (Fig. 2). In February 1997, there was 67.8 mm of rainfall, which was the highest in the 111-year period of record (Fig. 3). The mean February rainfall was 13.3 mm with a standard deviation of 15.6 mm. Based on a fitted exponential probability distribution, February rainfall between 65 and 70 mm would occur with an expected frequency of 0.21% (Fig. 3). Although soil temperatures were not cold enough to cause the poor winter survival (Table 1), the soil remained frozen. The highest value of the 0.05-m soil temperature measured at the weather site during February 1997 was -0.2°C. The average 0.05-m soil temperature on the plot also remained below 0°C during this period (Hayhoe and Andrews, 1999). This suggests that the soil remained frozen during February, which would have limited the infiltration of the large rainfall amounts. Observations on the plot indicated ice sheet formation to a depth of over 0.20 m (Hayhoe and Andrews, 1998).

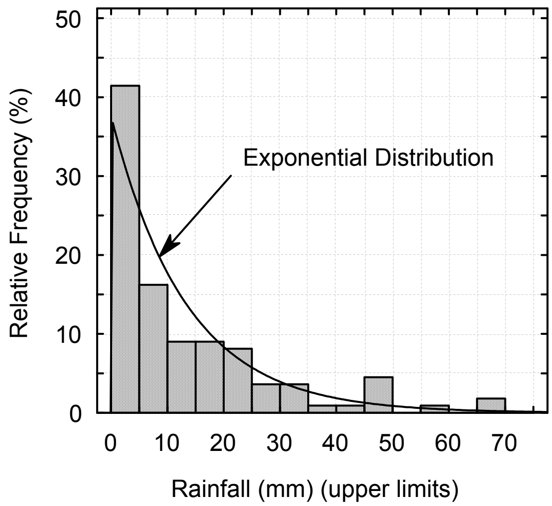

Figure 2. Frequency Distribution of the Total January Rainfall

The winter of 1999-00, which had winter survival 16.7%, had the lowest 0.05-m soil temperature measured during the 7-year experiment (Table 1). The median low temperature on the plot was -17°C. Temperatures were sufficiently low to cause winterkill (Savdie et al., 1991). These low temperatures were associated with conditions where there was little or no snow cover and air temperatures were less than -25°C. The lowest 0.05-m soil temperature measured at the weather site in January 2000 was –10.6°C. This was the lowest temperature measured at the 0.05-m depth during the 43 years of observations at the weather site (Fig. 4). Based on a fitted normal probability distribution, which is indicated by the solid line in Fig. 4, this low soil temperature would not be expected since the risk of a 0.05-m soil temperature less than or equal to -7°C was $3x10^{-5}$%. The extreme low soil temperature occurred on a day with 0.02 m of snow on the ground and a minimum air temperature of –25.5°C.

The low soil temperatures observed at the climatological station resulted from the cumulative effect of cold air temperatures and low levels of snow on the ground. The mean depth of snow on the ground for January for the period of record was 0.197 m with a standard deviation of 0.115 m. In January 2000, the mean depth of snow on the ground was 0.038 m with a standard deviation of 0.027 m and there were 4 days with no snow on the ground. The frequency distribution for the depth of snow on the ground in January at the weather site is shown in Fig. 5. Based on the 43-year period of record, the snow depth would be expected to be above 0.1 m 74% of the time. As a result of the poor snow cover in January 2000, soil temperatures were lower than normal. The mean 0.05-m soil temperature for January for the period of record was –0.56°C with a standard deviation of 1.6°C (Fig. 4). In January 2000, the mean 0.05-m soil temperature was –4.8°C with a standard deviation of 3.5°C.

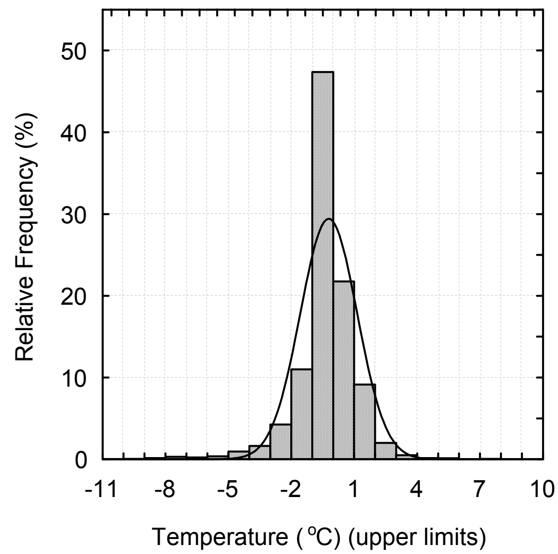

Figure 4. Frequency Distribution of the Weather Site Soil Temperature at the 0.05-m depth for December through March. The Solid Line Indicates the Fitted Normal Distribution.

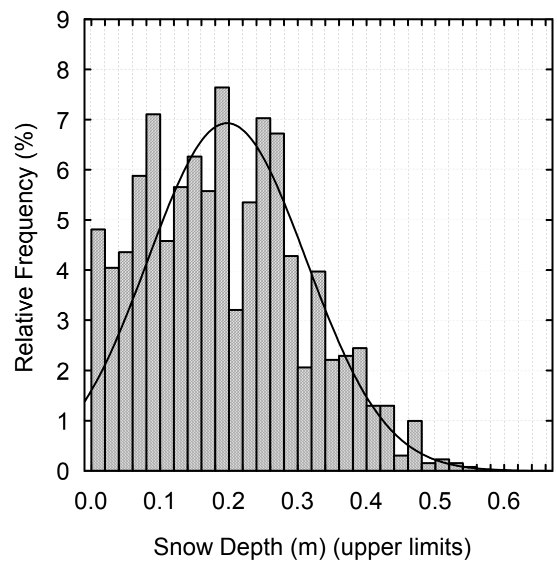

Figure 5. Frequency Distribution of the January Snow Depth at the Weather Site. The Solid Line Indicates the Fitted Normal Distribution.

4. DISCUSSION AND CONCLUSIONS

The seven years analysed in this study

included two years when most of the winter wheat on the plot was killed. In both years with less than 20% survival, extreme weather conditions occurred which previous research has suggested would lead to winterkill. The winter of 1996-97 experienced record rainfall on frozen soil. Above average rainfall occurred in December, January and February. The February rainfall was the highest observed in the 111-year period of record. An ice sheet formed on the plot to depth of over 0.20 m (Hayhoe and Andrews, 1998). Ice encasement of winter wheat plants is known to cause of winterkill. Ice encasement reduces respiratory gas exchange and allows the development of fermentative metabolism with the accumulation of damaging end products (Andrews and Pomeroy, 1979; Andrews, 1996). The winter of 1999-00 experienced record cold crown temperatures as indicated by the 0.05-m soil temperature at the weather site and on the plot. The 0.05-m soil temperature measured at the weather site was warmer than the corresponding values measured on the plot. Soil temperatures measured at the weather site were observed under a grass cover that would be expected to provide more thermal insulation than the plot temperatures measured on bare soil in an open field. The crown temperatures on the plot were sufficiently low to cause winterkill. Aase and Siddoway (1979) suggested that winter wheat plants could die at temperatures of -15 to -16°C.

We conclude that extreme weather events were the primary cause of winterkill in 1996-97 and 1999-00. The weather events were related to winter rainfall and snowmelt or cold air temperatures with little or no snow on the ground. The events appear to occur with greater frequency than would be predicted based means and standard deviation and fitted probability models. This study has identified extreme weather conditions that could be expected to cause winterkill. An analysis of the risk of these weather conditions occurring as a result of climate change or increased climate variability could contribute to impact assessments for winter wheat production.

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