Temperature variation and frost risk in undulating cropland

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Abstract

Temperature variation in undulating crop land was continuously monitored at thirty sites on two farms at Spring Ridge, in northern NSW. Monitoring began in June 1999 with Tiny Tag $_{TM}$ loggers exposed at screen height and recording at 15 minute intervals. Loggers were aligned in 5 transects varying by 15 to 93 m in altitude and from 0.5 to 6 km long. Surface characteristics (slope, aspect) were determined in ArcView. Temperature varied markedly with landscape position, lowest sites in all transects exhibiting lowest minima, highest cumulative hours < 2?C and < 0?C, longest duration of frost events and lowest degree day summations. Development in commercial wheat crops and in sown plots was delayed at lower sites, reflecting the lower temperature environment and resultant degree day accumulation.

Key Words

Frost, slope, aspect, landscape, digital elevation models, degree days.

Introduction

Damage from one or a few severe frosts during the critical flowering and grain filling stages causes severe economic loss to winter crop producers. Growers plant late to avoid frost damage, which may be a major threat on only part of their farm, but late planting carries an inherent yield penalty. Frost risk and severity is greater in summer rainfall regions such as Nth NSW and Sth Qld (4). On a regional scale, risks depend on prevailing weather conditions and hence season, synoptic patterns and latitude (4). At farm level, local variation in aspect, slope and altitude cause variation in temperature and frost incidence, even with little variation in topographic relief (1). The Wheatman decision support system (5,6) assigns frost risk on the basis of autumn SOI (4), but incorporating frost risk into cropping strategies requires specific on-farm temperature data.. Farmer use of minimum thermometers for this purpose is limited, as little benefit is perceived and only a single data point is recorded for each measuring period. These measurements give no indication of the timing and duration of damaging temperature exposure within a crop, which would require continuous monitoring. Little research has been done to characterise patterns of frost incidence on farm and there is considerable scope to use readily available topographic data in a Geographic Information System (GIS) (2), incorporate temperature data and then map variation in frost risk across the farm. This approach offers the potential to segment landscapes (3) into zones, enabling farmers to integrate frost into crop management strategies more effectively than at present. This paper reports research where temperature was continuously logged at 30 landscape positions over the 1999 and 2000 wheat seasons on two (B,C) undulating cropping farms at Spring Ridge, in NNSW, to investigate the effects of landscape position on temperature and, in particular, the incidence of frost.

METHODS

Thirty TinyTag IP68 temperature loggers (-40?C to +85?C range), recording at 15 minute intervals, were exposed at 1.5m height in mini-screens at 14 sites along 2 landscape transects on B and 16 sites along 3 transects on C in June 1999. Data have been logged continuously since installation. Location (x,y ?25 cm) and elevation (y ? 50 cm) of all sites were determined with a carrier phase differential GPS (global positioning system). Digitised aerial photographs were draped over 1:25,000 digital elevation models (dems) using ArcView Spatial Analyst to create digital terrain models (dtms) of each farm as base layers in the GIS. Slope (gradient %, length), aspect and flow lines were determined from each dtm in the GIS. The ArcView Hydro extension was used to predict flow direction and accumulation points for each farm, assuming that cold air drains similarly to water (1). Some loggers were subsequently relocated to predicted air sinks in August 2000. Logger sites and temperature parameters for each site were overlayed on the dtm to relate temperature variation to landscape. Three 5 m rows of each of two wheat cultivars (Sunstate and Sunbrook [short and long season respectively]) were planted at 2 sites on B and 4 sites on C on 1/5, 15/5, 29/5, 16/6, 25/6 and 23/7 in 2000 and development subsequently monitored to September 30.

Results And Discussion

Minimum temperature

Elevations and distance from crest (highest landscape point at top of slope) for selected sites in two transects on each farm are shown in Table 1. Transects were chosen to enable temperature measurement over a range of landscape variation from small (B) to moderate (C).

Table 1. Elevation (m a.s.l.) and distance from crest (km) for upper, mid and lower slope positions within transects. (Distance determined from dtm in ArcView).

		Farm			
		B		C	
		BT1	BT2	CT1	CT2
Upper	Elevation	376	366	430	393
	Distance	0.765	1.710	1.680	2.800
Mid	Elevation	370	360	385	369
	Distance	1.587	2.040	2.895	3.680
Lower	Elevation	361	351	357	337
	Distance	2.250	3.890	4.030	5.050

Landscape position had substantial effects on minimum temperatures recorded over both years and effects were consistent between years (Table 2). Data for early spring (August and September) in each year are shown in Table 2.

Table 2. Monthly average minimum temperature (?C), August and September 1999 and 2000, for the transects outlined in Table 1. (s.e. : standard error of treatment means).

Month	Transect

Month	Transect							
	BT1				BT2			
	Slope Position			s.e.	Slope Position			s.e.
	Upper	Mid	Lower		Upper	Mid	Lower	
August 99	2.5	1.8	0.7	0.98	3.4	1.7	0.8	1.02
August 00	2.5	1.9	0.8	0.72	3.5	2.1	1.7	0.73
September 99	5.4	5.0	4.1	1.10	6.6	5.0	4.6	1.07
September 00	3.4	2.7	0.9	0.70	4.8	2.6	2.0	0.73
	CT1				CT2			
	Slope Position			s.e.	Slope Position			s.e.
	Upper	Mid	Lower		Upper	Mid	Lower	
August 99	5.5	4.5	1.7	0.83	4.7	4.2	2.0	0.94
August 00	5.4	4.3	2.1	0.77	5.0	4.6	2.5	0.72
September 99	7.7	6.6	4.7	1.02	7.5	7.2	5.8	1.04
September 00	7.0	5.1	2.7	0.76	6.7	5.7	3.0	0.81

Minimum temperature declined significantly in all transects from upper to lower slope position, a result consistent with those of Kalma (1), indicating probable katabatic air drainage down slope, even on the slight slopes of BT1 and BT2.

Frost incidence and severity

Cold temperature events were recorded as frosts and severe frosts at screen temperatures of <2? C and <0? C respectively. Data for the four transects are shown in Table 3. Data shown are total number, hours and average length of frost events for August and September, averaged over the two years 1999 and 2000.

The effects of slope and landscape position on frost occurrence were consistent across all transects, regardless of slope or length, with lower slope positions recording much higher number, total exposure and average duration of exposure for all events. Farm B is known to be a colder location, presumably as a result of large scale regional air drainage, as general aspect is similar for both. Cotton is grown successfully on C, but is considered marginal for B because of its colder temperature regime.

This is supported by the recorded differences between the transects on the two farms, with BT1 and BT2 both showing consistently greater frost exposure, both in terms of incidence and severity.

Table 3. Average for 1999 and 2000 of total number, total hours below $0^{o\ C}$ and 2^{o} C, and mean event duration for August and September along the four slope transects.

Transect	Slope Position	Number of Events		Total Hours		Mean Event Duration (hours)	
		< 0? C	< 2? C	< 0? C	< 2? C	< 0? C	< 2? C
BT1	Upper	12	22	27	92	2.3	4.3
	Mid	15	27	56	125	3.7	4.6
	Lower	24	33	105	188	4.4	5.7
BT2	Upper	6	13	7.3	45	1.2	3.5
	Mid	15	26	45	108	3.0	4.2
	Lower	18	30	75	148	4.2	4.9
CT1	Upper	2	4	2	10	1.0	2.5
	Mid	3	10	7	30	2.4	3.0
	Lower	17	27	59	120	3.5	4.4
CT2	Upper	1	9	3	20	1.5	2.2
	Mid	4	12	6	34	1.5	2.8

Lower	16	23	52	106	3.3	4.6

Farmer perception of frost occurrence was generally limited to direct observation and seriously underestimated both frequency and severity, particularly in 1999, which was a relatively wet year, regarded by them as largely frost free. Temperatures often fell to frost levels in the early morning hours and persisted for periods of up to 12 and 14 hours for temperatures below 0? and 2? respectively, although average duration was considerably less than this (Table 3). Duration of individual frost events ranged from 15 minutes to several hours, with consistently longer and colder frost periods at lower slope positions. Individual events had median durations between 3 and 6 hours for all transects, with lower slope sites exhibiting longer average duration and lowest temperatures in all cases.

Date of last frost

Position in the slope had little effect on date of last frost in most cases, with both BT transects differing by only one day for upper and lower slope sites in both years. Average dates of last frost for all BT sites were 20/9/1999 and 14/9/2000. The same dates were recorded on the steeper CT slopes 1999, but in 2000 the last date of severe frosts at upper positions (August 17th) was one month earlier than at lower ones (September 14th). The 2000 results suggest that position may have an important influence on date of last frost, but mainly on the steeper slopes. Little difference was recorded between last dates of severe versus mild frost in most cases, suggesting that slope position and air drainage were secondary to general weather conditions conducive to frost development.

Temperature and crop development

Degree day summations (base temperature 2**?** C) for the period July to September in each year are shown in Table 4. In all cases, degree day totals were greater at upper than at lower slope positions, reflecting the lower temperature environment at the lower slope sites.

Observations of development in adjacent commercial wheat crops in 1999 revealed slower development at the lower sites, with plants at upper sites ranging from heading to mid-anthesis while those at the lower sites were in early boot to early heading. Wheat plots sown serially in 2000 showed similar effects, lower slope positions showing development retarded by as much as 7 days compared to upper slope sites. Similar effects were again observed in adjacent commercial wheat crops.

Table 4. Degree day summations for July – September in 1999 and 2000 (base temperature 2? C).

	BT1			BT2		
	Slope Position			Slope Position		
	Upper	Mid	Lower	Upper	Mid	Lower
Jul 1-Sep 30 99	845	828	810	924	848	807
Jul 1-Sep 23 00	687	680	604	761	697	632

	CT1			CT2		
	Slope Position			Slope Position		
	Upper	Mid	Lower	Upper	Mid	Lower
Jul 1-Sep 30 99	1004	975	906	981	998	952
Jul 1-Sep 23 00	806	757	685	788	797	729

General discussion

Within slopes, cold air drainage (1) causes considerable cooling of lower locations. Slope length and gradient appear to be the most important controls of drainage and resultant cooling. Preliminary analysis using a water drainage model in ArcView indicates that relative position within the total length of a slope may be a key determinant of cumulative drainage effects and resultant temperature at any point.

Indigenous farmer knowledge of low lying, colder areas on farm is recognised in the practice of sowing such land last to reduce the risk of frost damage. The greater incidence and severity of frosts at lower locations within slopes may be partially offset by delayed crop development in these cooler locations.

Conclusions

Frost incidence and severity varies markedly within and between slopes, and within a landscape, cooling appears to reflect drainage from higher to lower levels along drainage paths determined by the local topography. Generalised relationships between landscape attributes, derived from digital elevation models, and air drainage patterns offer promise for development of predictive models for improved management of frost risk within cropped landscapes.

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