Environmental Indicators of Agricultural Drought Impacts on Spring Wheat in Western Canada

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Introduction

Droughts are the world's costliest natural disaster collectively affecting more people than any other form. Most regions of Canada have experienced drought, however, the Canadian prairies are more susceptible mainly due to high precipitation variability both spatially and temporally. Droughts develop slowly and are difficult to quantify in terms of spatial extent and intensity. The success of drought preparedness and mitigation depends, to a large extent, upon timely information on drought onset, progress and extent.

Drought monitoring is normally performed using drought indices to provide policy makers with timely information on drought extent and severity. Examples of ongoing drought monitoring programs include the Drought Watch by Agriculture and Agri-Food Canada (AAFC), the U.S. Drought Monitor, the North American Drought Monitor and the National Agricultural Monitoring System for Australia. Precipitation indices alone may not provide the most accurate indications of drought impacts on crops.

The objective of this study was to evaluate a range of moisture-based indices over different periods of the growing season to determine which most accurately reflected the impact of growing season weather on the yield and quality of western Canadian spring wheat.

Materials and Methods

Six spring wheat cultivars were grown in nine locations across the Canadian prairies during the 2003 through 2006 growing seasons, providing a very diverse range of growing environments. Cultivars were selected to encompass a range in wheat milling and baking quality characteristics. For this study, results from two key genotypes, AC Barrie and Superb, were utilized. Field sites were established at Regina, Melfort and Swift Current in Saskatchewan and at Winnipeg and Carman in Manitoba. The experimental layout in each location was a randomized complete block design with three replicates (Fig. 1).

At each location, phenological observations of wheat development stages were recorded every 10 to 15 days for each plot using the Zadoks decimal code. Dates of emergence, dates of anthesis, and dates of maturity were also recorded. Automated weather stations were installed at each site to monitor air and soil temperature, rainfall, wind-speed, relative humidity, solar radiation, and soil moisture on an hourly and daily basis.

Wheat Grain Yield and Quality Analysis

At maturity, plots were harvested and grain samples from each plot were graded by the Canadian Grain Commission. Grain yield was expressed at 13.5% moisture basis. Wheat grain protein concentration (GPC) was determined using Near-Infrared Reflectance Spectroscopy (NIRS). Other grain quality parameters including farinograph absorption, farinograph dough absorption time and loaf volume were determined following standard procedures.

Agrometeorological Analysis

Drought indices were calculated from the meteorological and soil moisture data and categorised as (i) Water Supply, (ii) Water Demand, or (iii) Water Balance indices.

The water supply indices monitor the amount of precipitation received and included (1) Accumulated Precipitation, (2) Percent of Normal Precipitation, and (3) Standardised Precipitation Index.

The water demand indices used evapotranspiration (ET) as an indicator of drought. These included reference (ETo), standard (ETc) and potential (ETp) calculated using different methods i.e. Hargreaves et al. (1985), Allen et al. (1998) and Raddatz (1993).

The water balance indices assessed either the accumulated water deficit (i.e. plant available soil moisture at planting plus (+) precipitation accumulated from planting to a specific point in the growing season minus (-) ETc accumulated from planting to the same point) or used a simple 2-layer soil moisture model to determine daily soil moisture availability for the purpose of calculating daily crop water use.

Indices were accumulated over various periods including monthly, bimonthly, tri-monthly, May through August as well as over specific wheat growth periods including planting to anthesis, (P-A) anthesis to maturity (A-M) and planting to maturity (P-M).

Fig. 1: Plot experiments at different wheat growth stages and weather recording instruments.

Statistical Analysis

A correlation matrix was utilised to assess relationships between wheat yield and quality parameters and each drought index. The analysis was done separately for the two genotypes to determine whether responses varied by cultivar. Linear regression was used to identify statistically significant regression equations ($P<0.05$).

Results

Tables 1 and 2 show drought indices with statistically significant ($P<0.05$) correlation coefficients (r) for grain yield, grain protein concentration, farinograph absorption, farinograph dough absorption time and loaf volume for the two cultivars. Grain yield for both cultivars was negatively correlated to PETc (Fig. 2) and PETo (both water demand indices) with r values ranging from -0.53 to -0.59. The best correlation period was P-A then P-M.

For both cultivars, grain protein concentration was highly correlated to water demand and water balance indices with r values ranging from -0.52 to 0.76. The best correlation period was P-A, followed by P-M then A-M.

Farinograph absorption for AC Barrie was negatively correlated to water demand, while that for Superb was negatively correlated to water balance and water demand. The r values for AC Barrie ranged from -0.52 to -0.54, while those for Superb ranged from -0.52 to -0.60. The best correlation period for AC Barrie was P-M and A-M, while that for Superb was the month of August and A-M.

Farinograph dough absorption time for both cultivars was highly correlated to water demand and water balance indices with r values ranging from -0.52 to 0.86. The best correlation period was P-A followed by P-M and A-M.

Loaf volume for both cultivars was positively correlated to water demand with r values ranging from 0.58 to 0.69. The cultivar Superb was also negatively correlated to water balance with r values ranging from -0.55 to -0.66. The best correlation period was P-A followed by A-M and P-M.

Table 1: Drought indices with statistically significant correlation coefficients (r) for yield and wheat quality parameters for AC Barrie

Grain Parameter	Index	Time Period	r
Grain Yield	PETc	Planting-Anthesis	-0.54*
	PETo	Planting-Anthesis	-0.54*
	PETo	Growing Season	-0.53*
Grain Protein Concentration	PETo	Planting-Anthesis	0.71**
	HETo	Planting-Anthesis	0.68**
	PETo	Growing Season	0.66**
	HETa	Anthesis-Maturity	-0.65**
	HETo	Growing Season	0.64*
	PETc	Planting-Anthesis	0.62*
	PETa	Anthesis-Maturity	-0.60*
	HETa	Growing Season	-0.56*
	PETc	Growing Season	-0.55*
Farinograph Absorption	HETa	Growing Season	-0.54*
	HETa	Anthesis-Maturity	-0.52*
Farinograph Dough Absorption Time	PETc	Growing Season	0.77**
	PETc	Planting-Anthesis	0.75**
	HETc	Planting-Anthesis	0.62*
	PETc	Anthesis-Maturity	0.61*
	HETa	Anthesis-Maturity	-0.57*
	HETo	Planting-Anthesis	0.57*
	PWdef	Growing Season	-0.56*
	PETa	Anthesis-Maturity	-0.56*
	HETc	Growing Season	-0.54*
	PETo	Planting-Anthesis	0.54*
	PWdef	Planting-Anthesis	-0.52*
Loaf Volume	HETo	Planting-Anthesis	0.62*
	HETo	Growing Season	0.60*
	PETo	Planting-Anthesis	0.58*

Table 2: Drought indices with statistically significant correlation coefficients (r) for yield and wheat quality parameters for Superb

Grain Parameter	Index	Time Period	r
Grain Yield	PETc	Planting-Anthesis	-0.59*
	PETo	Planting-Anthesis	-0.55*
	PETo	Growing Season	-0.53*
Grain Protein Concentration	PETo	Planting-Anthesis	0.76**
	HETa	Anthesis-Maturity	-0.76**
	PETc	Planting-Anthesis	0.74**
	HETo	Planting-Anthesis	0.68**
	PETo	Growing Season	0.67**
	PETa	Anthesis-Maturity	-0.63**
	HETa	Growing Season	-0.61*
	PWdef	Planting-Anthesis	-0.59*
	PETc	Growing Season	0.59*
	PWdef	Growing Season	0.56*
	HETo	Growing Season	0.53*
	2Wdef	Planting-Anthesis	-0.52*
	HETc	Planting-Anthesis	0.52*
	2PE	Planting-Anthesis	0.52*
Farinograph Absorption	SPI	August	-0.60*
	Precip	August	-0.59*
	HETa	Anthesis-Maturity	-0.59*
	Precip Normal	August	-0.52*
Farinograph Dough Absorption Time	PETc	Growing Season	0.86**
	PETc	Planting-Anthesis	0.84**
	HETc	Planting-Anthesis	0.73**
	HETo	Planting-Anthesis	0.72**
	PETo	Planting-Anthesis	0.69**
	PETc	Anthesis-Maturity	0.68**
	HETc	Growing Season	0.66**
	PWdef	Growing Season	-0.59*
	2PE	Planting-Anthesis	0.58*
	HWdef	Growing Season	-0.52*
	HETa	Anthesis-Maturity	-0.52*
Loaf Volume	PETo	Planting-Anthesis	0.69**
	HETa	Anthesis-Maturity	-0.66**
	PETo	Growing Season	0.66**
	HETo	Planting-Anthesis	0.61*
	PETc	Planting-Anthesis	0.58*
	HETo	Growing Season	0.58*
	PETa	Anthesis-Maturity	-0.58*
	PWdef	Planting-Anthesis	-0.55*

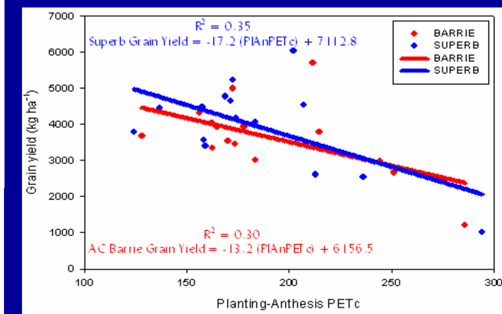

Fig 2. Relationship between grain yield (both cultivars) and PETc (planting to anthesis).

Conclusions

Statistically significant indices explained between 27% and 74% of the variation in wheat yield and four different wheat bread-making quality parameters for the two wheat cultivars. The drought index category most highly correlated to the greatest number of wheat characteristics was water demand (63%), followed by water balance (32%) and water supply (4%). The modified Penman-Monteith method of estimating ET was the best of the water demand methods. Drought indices accumulated from planting to anthesis were superior (44%) to those accumulated over the entire growing season (32%) and those accumulated from anthesis to maturity (19%). These results suggest that drought indices focusing on ET and water demand may provide the most accurate reflection of drought impact on spring wheat yield and quality in western Canada.

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