Spatial Variability of Boron Availability in Canola

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Abstract

The spatial variability of hot water soluble boron (HWS-B) and yield responses of canola to B fertilization was assessed at sites in the Grey soil Zone using a linear sampling transect. At each site, 128 soil samples were taken at 3-meter intervals and analyzed for HWS-B, physical and chemical soil properties. Results indicate that the organic matter content, particularly in acidic soils, strongly influenced HWS-B content. To a lesser extent, soil pH and texture also contributed to HWS-B variability. On the alkaline site, apparent yield increases to foliar B were correlated to soil pH in a positive and significant manner. The HWS-B test failed to predict the yield responses to B fertilization. In the year of the study eat and drought stress occurred during a period when canola is most sensitive to a B deficiency (flowering) and also may have contributed to the yield increases. Results of a geostatistical analysis, known as wavelet analysis, revealed that at spatial scales > 50m, variability in HWS-B content is significant. Therefore, significant responses to B fertilization may not be detected with the traditional random complete block design.

Introduction

Micronutrients are of equal importance to macronutrients (e.g., N, P, K and S) for overall plant nutrition but are required in smaller amounts. Deficiencies of micronutrients, such as boron (B), have already become a widespread nutritional problem in over 70 countries worldwide (Rashid et al., 1994; Shorrocks, 1991). In Saskatchewan, B fertility is of considerable interest because it has not been extensively studied. Continual advancements in producing high-yielding plant varieties in combination with relatively intensive agricultural practices may lead to nutrient depletion of soils.

Results from other studies led to the suggestion that canola may not be responsive to B in Saskatchewan soils. As a consequence of the research design used, it is possible that B deficiencies have not been detected in Saskatchewan (when a random complete block design was used) due to the spatial variability of B availability. We proposed that using a transect design, coupled with geostatistical analysis and a quantification of the relationship between soil characteristic that control canola yield responses to B will improve soil B deficiency diagnosis.

Materials and Methods

Two experiments were conducted in commercial fields at Carrot River and Smeaton, SK. At each site, a (8.0 m x 384 m) transect was established across the field.

The transect was comprised of a control (no-B) strip, flanked by two B fertilizer stripes. Two 1.0 m buffer strips were placed between the control and treated strips to prevent any cross contamination. Soil samples from 128 points were collected along the transect at regular (3 m) spacing to depths of 0 to 15 and 15 to 30 cm from within the control strip. Physio-chemical properties such as organic carbon, inorganic carbon, electrical conductivity, pH, texture and HWS-B were determined.

On May 17, 2002, the Carrot River transect was seeded to canola (*Brassica napus L.* cv. 45A77) at a rate of 5 kg ha^{-1} using a commercial-scale air drills (30 cm spacing with 10 cm spread). On May 22, 2002, the Smeaton transect was seeded to canola (cv. 46A76) at a rate of 6.7 kg ha^{-1} using a press drill (15 cm spacing). On May 24th, one strip of the Smeaton and Carrot River trials received B at a rate of 2 kg B ha^{-1} (Granubor) as a broadcast treatment. The second strip receive B as a foliar application on June 26th at Carrot River and Smeaton July 5th site. The foliar B was applied at the BBCH53 (inflorescence emergence of main shoot with flower buds raised above leaves) growth stage at a rate of 0.5 kg B ha^{-1} with a surfactant (Agsurf at 4 ml L^{-1}).

At crop maturity, a 1m^2 section was hand-harvested from each of the seeded strips for determination of grain yield and total biomass, at each of the 128 sampling points.

Statistical Analysis

A stepwise (add-delete) regression model for soil and yield parameters was used to examine the data. This multiple regression model relates a dependent variable Y to a set of quantitative independent variables μ. The multiple regression model is as follows:

$$Y_i = b_0 + b_1\mu_1 + b_2\mu_2 \ldots + b_n\mu_n + e_i$$

Where Y_i is the response or dependent variable (i.e. grain yields and HWS-B contents), b_0 is the intercept (defined as the variation not contributed by the soil variables), $b_1 - b_n$ is the regression coeffiecents, μ_1 - μ_n is the assumed independent factor (soil parameter value at each sampling point), e_I is the independent random error with normal probability distribution, zero mean and uniform variance (SAS Inc. version 8, 2000).

The objective of the stepwise technique is to take a set of independent variables and put them into a regression one at a time until the inclusion significantly ($p<0.05$) improves the quality of the model or excluded if their removal does not significantly decrease ($p<0.1$) it.

A correlation (Pearson) analysis was used to provide a measure of strength of the relationship between the dependent variable (yield and HWS-B content) and independent variables (soil properties).

Wavelet analysis is a relatively new method for studying time-frequency localization (Morlet et al., 1988). This analysis allows one to study features on the spatial series locally with a detail matched to their scale (i.e., broad features on a large-scale and fine features on small-scales) (Si, 2003). Wavelets are useful for spatial variations that are nonstationary, passing components and features at different scales. Previous authors (Lark and Webster, 1999, 2001) have applied wavelet analysis in soil science to reveal strongly contrasting local features of variation. Wavelet correlations were used to describe scale dependence in the correlation of two variables. In this study, continuous wavelet analysis in nonstationarity fields was used to demonstrate the advantage of wavelet analysis through analytical signals. Then, the wavelet transform was applied to the analysis of spatial variation of B availability.

Results and Discussion

Average soil properties (across all 128 sampling point) for the two fields are shown in Table 1.

Table 1. Average physio-chemical prepares (0-15 cm / 15-30cm) depth of Carrot River and Smeaton transects.

Properties	Units	Values			
		Carrot River		**Smeaton**	
		0-15 cm	15-30 cm	0-15 cm	15-30 cm
Sand	%	75	76	67	64
Silt	%	11	11	22	23
Clay	%	14	13	11	13
Textural class	-	sandy loam	sandy loam	sandy loam	sandy loam
pH		7.9	8.2	5.8	6.8
Electrical conductivity	$mScm^{-1}$	236	211	164	114
Organic carbon	%	2.9	0.4	0.7	0.2
Inorganic carbon	%	0.5	0.5	0.4	0.2
HWS-B	mg kg^{-1}	0.77	0.20	0.24	0.15

Relationship between HWS-B and soil properties

Organic matter significantly describe 82% of the variation in HWS-B content on the Smeaton transect (Table 2, Fig. 1). Similarly, Gutpa (1968) similarly found that HWS-B was positively related to the organic matter content of soils. HWS-B is considered as a good indicator of plant available B and therefore supports the theory that organic matter is the main reserve of B easily available to plants through mineralization (Gupta et al., 1985). Okazaki and Chao (1968) reported that organic matter is one of the main sources of B, especially in acidic soils, such as those found at the Smeaton site.

Table 2. Results of stepwise regression of basic soil properties and hot water extractable B, and various yield parameters Smeaton transect (0-15 cm depth).

Variable	Parameter estimate	Standard error	Type II SS	F-value	Partial R^2	Model R^2
HWS-B						
Intercept	-0.31	0.03	<1	115.45***		
Organic carbon	0.18	0.01	<1	196.11***	82	82
PH	0.06	0.01	<1	105.07***	7	89
Inorganic carbon	0.12	0.02	<1	55.58***	4	93
Electrical conductivity	0.00	0.00	<1	5.38*	<1	93
Clay	0.00	0.00	<1	5.35*	<1	93

*** p<0.001; *p<0.05

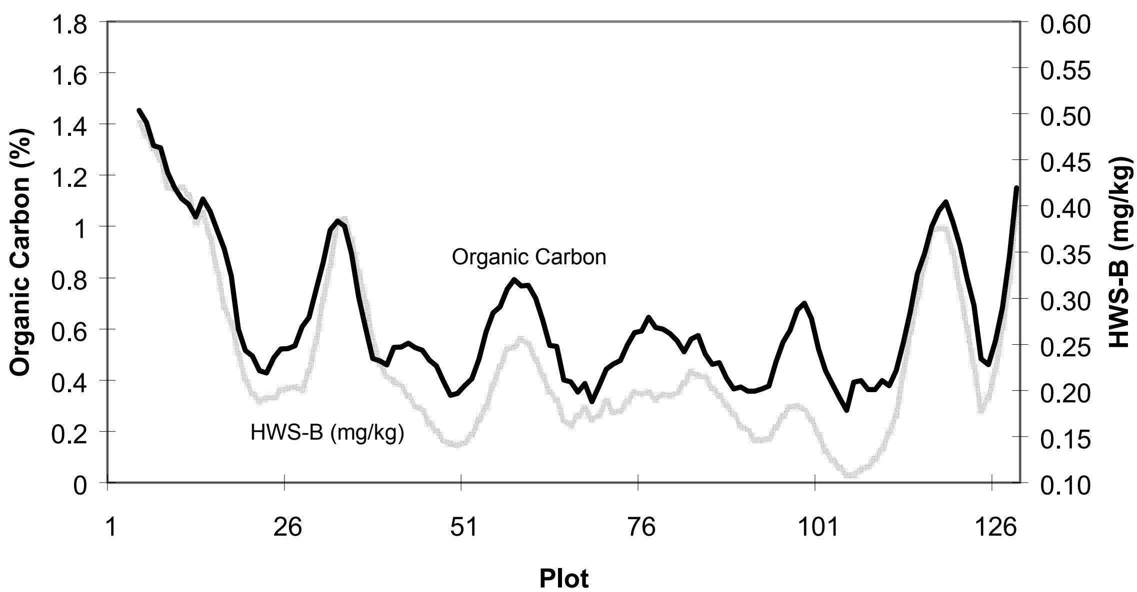

Figure 1. Organic carbon (%) and HWS-B (mg/kg) content of the Smeaton transect (0 to 15 cm depth).

The stepwise regression analysis indicated that soil H enhanced the regression model (7%). Moreover, a positive correlation (r = 0.78) between HWS-B and pH suggests the B availability increases with pH in acidic soils. Relatively little adsorption of B occurs at low pH levels because B is mostly in an unabsorbed boric acid form. Berger and Troug (1945) reported that from pH 4.7 to 6.7 the available B in cultivated soils increased. They demonstrated a direct positive relationship with available B and percent organic matter. They concluded that, in acid soils, organic matter had a large influence on available B. Based on correlation and regression data of the Smeaton transect, our results are in agreement with these earlier observations. Wear and Patterson (1962) observed that more B was available at all levels of water-soluble B in all soil types as pH increased from 5 to 7. They concluded that water-soluble B content of soil is a good indicator of plant available B when soils of similar texture and pH are considered. Soil pH and HWS-B seem to follow a similar trend.

The inclusion of inorganic carbon into the HWS-B model may indicate its importance as a B adsorbing surface that is extracted in the HWS-B test (Goldberg and Forester, 1991).

Pinyerd et al (1984) reported that in a coarse-textured and low organic matter soil Ultisol, the distribution of HWS-B was well correlated to clay content. Although, percent clay only adds <1% to the model R^2, clay was positively correlated to HWS-B ($r = 0.652$) in a similar soil found in the Smeaton site. The correlation with percent clay may be partially explained through its close relationship with soil organic matter ($r = 0.635$).

Relationship between Δ-grain yield and soil properties

Response to B fertilization was assessed by calculating the change in yield due to B treatment (i.e., treatment yield minus control yield), denoted 'Δ-yield' at each sampling point (Table 3). In the foliar Carrot River Δ-yields, pH contributed to variation in a positive and significant manner (data not shown), although pH accounted for 6% of model R^2 and thus may be of little agronomic significance. Irrespective of the agronomic significance, the positive and significant relationship suggests that with increasing soil pH, in an alkaline soil, there are also significant increases in yield response to foliar B fertilizer. This may be explained through the impact of soil pH in regulating the release of HWS-B from soil constituents. As the pH rises above 7, the concentration of borate $B(OH)_4^-$ entering solution rises but it also becomes less available to plants due to increased adsorption (Gupta et al., 1985). The pH range for the Carrot River transect was pH 6.6 to 8.4. With increasing soil pH, there was an increase in the response to foliar B fertilizer along much of the transect (Fig 2.). Deviations form this relationship likely reflect the influence of a factor or factors that override the impact of the pH on yield response. These data suggest that B-response to B fertilization may be highly variable within a field, depending on variations in organic matter and pH.

Table 3. Average yield and biomass of granular, foliar and control a treatment in entire Carrot River and Smeaton transects. Percent increase or decrease over control treatment in brackets.

Site	Measurement	Foliar (A)	Granular (B)	Control (C)	Δ (A-C)	Δ (B-C)
Carrot River	Grain Yield (kg ha^{-1})	867	900	730	137(19%)	169(23%)
	Biomass (kg ha^{-1})	5102	5208	4695	407(9%)	513(11%)
Smeaton	Grain Yield (kg ha^{-1})	901	1121	994	-93(-9%)	127(12%)
	Biomass (kg ha^{-1})	4954	5548	5278	-324(-6%)	270(5%)

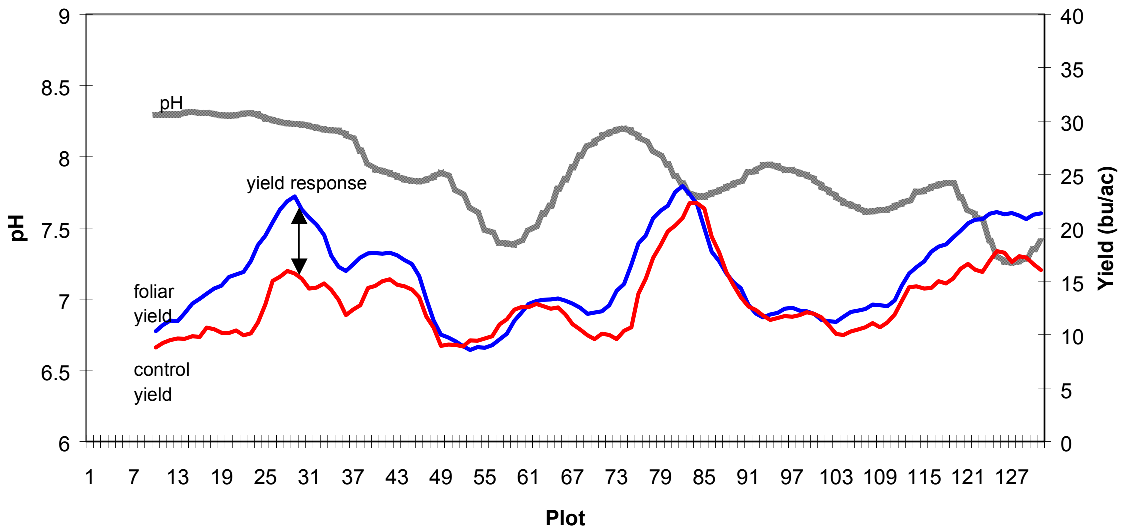

Figure 2. Trendline for foliar yield, control yield and soil pH of the Smeaton (0-15cm).

Environmental factors may have accounted for a portion of the yield variation that was not identified through analysis of soil properties. Heat and drought stress affects the incidence and severity of B deficiency more than any other micronutrient, especially during flowering (Moragan and Mascagni, 1991). In both sites during the month of July, the mean temperatures were greater, and monthly precipitation was much lower, than the 30-year average. A B deficiency is most likely to occur under low soil moisture conditions, in part due to the reduction of B movement by mass flow to the root (Gupta et al., 1985). In addition, microbial activity ceases when the soil water content is near wilting point (Thompson and Troeh, 1978). A large amount of total B is held by organic matter and is released upon microbial degradation (Flemming, 1980). Low moisture contents can greatly reduce microbial activity and thus the B remains complexed and unavailable to plants.

Boron plays a major role in canola formation of flowers, successful fertilization and filling of the seed with sufficient storage material (Asad et al., 1997). Severely impaired seed set and sterility are late-season symptoms of B deficiency in both B sensitive (e.g., canola) and B insensitive (e.g., wheat) crops (Havlin et al., 1999). These symptoms appeared to be similar to the symptoms observed in the Carrot River transect. Visual indications were increased floret sterility in the control treatment over the foliar and granular treatments. It is possible that floret sterility was possibly attributable to low B supply due to heat and drought stress during a period in which the canola plant was most sensitive to a B deficiency (flowering) (Asad et al., 1997). The total number of flowers produced by canola may be increased by B fertilization (Myers et al., 1983). The application of B was observed by Nuttal et al. (1987) to prevent sterile florets and to increase seedpod development in a field experiment in Melfort, Saskatchewan.

HWS-B Wavelet Spectrum (Carrot River 0-15 cm)

The goal of the wavelet analysis is to explain scale-dependence in the correlation between two variables and to identify areas that differ in respect to the correlation between to variables (Fig. 3). The local wavelet spectrum (Fig. 3b) for HWS-B revealed two scales of variation across the transect of 0 to 50 m and 50 to 300 m (300 m max. scale resolvable by wavelet analysis for this study). For the 0 to 50 m scale, high variance were centered around the transect at 50, 75, 100, 180, 240, 270, 330, 360 m. These regions correspond to areas of high and low organic matter content (Fig. 3a) and indicate the presence of a global feature.

For the 50 to 300m, high variance positions were centered around 180 m and 270 m. These regions also correspond to the highest and lowest organic matter content position in the transect. The global wavelet spectrum was obtained by integrating the local wavelet spectra across the transect (Fig. 3c). Spatial variation < 50 m were not significantly different at a confidence level of 99% from that of white noise, or random variability. Therefore, variability at a spatial scale of < 50 m was considered random at the Carrot River site. At spatial scales > 50m, variability in HWS-B at the Carrot River site is significant. Smeaton also displayed a similar scale of 50 m (not shown), also though the scale of variability is likely site and field specific.

Mean HWS-B content of the transect was greatest at positions where organic carbon was highest. High organic matter soils resulted in strong small-scale spatial variation in the HWS-B content. As, a result, strong amplitude change would be expected for those locations, resulting in high wavelet variance. The alteration of low to high organic matter content results in large amplitude, and thus large variance. It can be concluded that the periodic variation in HWS-B content reflected the pattern of organic carbon.

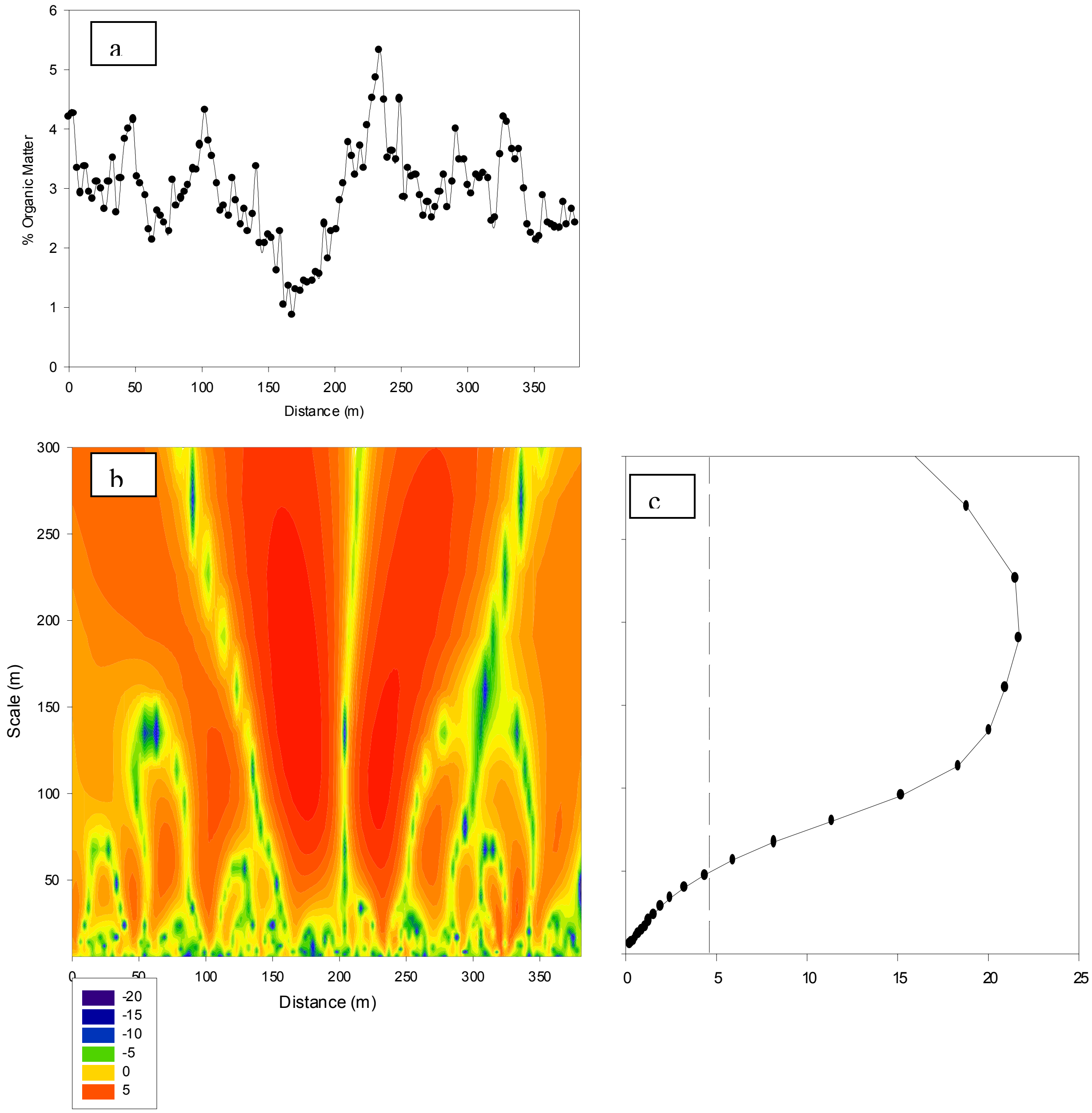

Figure 3. Wavelet spectrum of HWS-B across the Carrot River transect (0-15 cm)

Summary

This study is yet to be finalized, but a number of inferences can be drawn. The soil properties that appear to have an impact on HWS-B content are in decreasing order of importance: organic matter >> pH > clay > inorganic carbon. HWS-B failed to give an accurate indication of plant available B in that it was not related to canola yield or canola yield response. At the alkaline site (Carrot River), soil pH was positively and significantly related to the yield responses due to foliar B fertilization. In addition to soil properties, hot and dry environmental conditions and physiological importance of B during flowering of canola likely also played a role in explaining the apparent yield responses. Results for the wavelet analysis indicated that at spatial scales > 50m, variability in HWS-B is significant in that periodic variation in HWS-B content reflected the pattern of organic carbon.

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