CHAPTER 24

Sulphur Deficiency Uncovered: British Columbia Experience

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Sulphur deficient alfalfa (light areas) growing on eroded slopes in Ontario. PHOTO BY BONNIE BALL | OMAFRA

A world-wide issue

Sulphur (S) is an essential plant nutrient present in proteins, enzymes, vitamins, hormones and a variety of other constituents (Mills and Jones 1996). It is also important for symbiotic nitrogen (N) fixation by promoting nodule formation. Although plants need a significant amount of S, about the same as phosphorus (P), S fertilizer is not frequently applied, suggesting that agricultural crops tend to have adequate supplies. In industrialized areas (and near oceans) significant amounts of S have been deposited in precipitation (Arnold and Stoeppler 2004). However, concern is increasing world-wide that S is limiting crop production as S deposition is declining due to controls on emissions. Also, there is increasing economic pressure to mitigate all causes of suboptimal production on crop land (Scherer 2001, 2008; Jez 2008). While S research has focused on high value crops, there is growing evidence of S deficiencies in forages in many locations, such as alfalfa in New York State (Ketterings et al. 2012).

Deficiencies in British Columbia forages

The need for S fertilizer for alfalfa was first documented in the arid interior of British Columbia (BC) in 1974 field trials (Table 1; Kowalenko 1993) and S deficiency in grasses was demonstrated in 1979 in the humid south coast region of BC (Kowalenko 1984). Previously, it had been assumed that there was adequate S in coastal soils due to deposition from the oceanic and anthropogenic sources. Follow-up trials across the Lower Fraser Valley region in 1980 showed that S application increased yield of forage grass in two fields, did not have a significant effect in four fields, and

Table 1. Yield responses of second year alfalfa to gypsum applications in interior BC in 1974.

Location	Response	Time applied
Kelowna	**No**	Fall 1973
Prince George	**Yes**	Fall 1973
Prince George	**Yes**	Fall 1973
Quesnel	**Yes**	Fall 1973
Quesnel	**Yes**	Fall 1973
Westwold	**No**	Fall 1973
McLure	**Maybe**	Fall 1973
Okanagan Falls	**Maybe**	Spring 1974
Rock Creek	**Maybe**	Spring 1974
Rock Creek	**No**	Spring 1974
Enderby	**No**	Spring 1974
Buffalo Creek	**No**	Spring 1974

Table 2. Summary of crop responses to sulphur applications in the Lower Fraser Valley, BC.

Site - year	Crop	Relative yield response
Agassiz (Farm #2) - 1979	Orchardgrass	1.74*
Agassiz (main farm) - 1980	Orchardgrass	1.05
Agassiz (Farm #2) - 1980	Orchardgrass	1.13*
Deroche - 1980	Orchardgrass	1.05
Mount Lehman - 1980	Orchardgrass	1.06
Cloverdale -1980	Perennial ryegrass	0.85*
Arnold - 1980	Orchardgrass	1.26*
Yarrow - 1980	Orchardgrass	1.05

* Significant effect of sulphur at P<0.05.

reduced yield in one site for unknown reasons (Table 2; Kowalenko 2004). Detailed examination of the yield effects in the 1979 grass trial showed that yield and plant concentration responses to S were greater in the spring and fall than in the summer (Table 3; Kowalenko 2000). Response to S was much greater where N was also applied (significant interactions with N). The interaction of S and N was complicated with a synergistic effect in the spring and an antagonistic effect in late summer. It is now surmised that crop responses to the popular Sul-Po-Mag fertilizer in coastal BC were due more to the S than the K or Mg components. As the need for fertilizing crops with S is gaining recognition, there is a growing demand for an effective test to predict fertilizer response.

Developing soil tests

Both plant and soil analyses have been evaluated for predicting the need for S fertilizer. Plant analysis requires relatively mature plants and thus occurs too late for effective remediation. The initial soil S test involved $CaCl_2$ extraction with sulphate-S measured by reduction with hydriodic acid (Kowalenko 1993). The multi-element Kelowna extractant was introduced in BC in the early 1980s and analysis was conducted by Inductively Coupled Plasma Spectrometry. The new soil test determined significantly more S than the previous one (Table 4).

The different amounts of S measured by the two methods can be explained by the forms of S in soils. Typically, more than 95% of soil S is in organic form and not available to plants until it is mineralized to an inorganic sulphate (Scherer 2001, 2009). The negatively charged sulphate ion is the predominant inorganic form of S in most soils. Because of their negative charge, sulphate ions are not adsorbed to soils which are generally negatively charged, with the exception of acidic soils which can be positively charged from presence of excess H+ ions. Water or weak salts (e.g. $CaCl_2$) will extract “free” (unadsorbed) sulphate whereas solutions containing anions that displace adsorbed sulphate (e.g. phosphate) extract both adsorbed and unadsorbed sulphate. Since the Kelowna solution is relatively concentrated and includes anions (acetate and fluoride), it extracts both adsorbed and unadsorbed sulphate, hence gives greater values than extraction with the weaker salt ($CaCl_2$) solution. The availability to plants of adsorbed sulphate is still unclear.

Other soil test solutions (e.g. sodium bicarbonate, phosphate or acetate solutions “S”, Mehlich-3) extract variable quantities of S and their ability to predict plant response in coastal BC is not well-known (Kowalenko 2004, 2008). Hot KCl extract can be used to decompose labile organic S potentially available to plants (Blair et al. 1993) but this method is unproven in BC.

The method of quantifying the extracted S is also important for interpreting the concentration values. Historically, sulphate was measured by either barium precipitation or

Table 3. Yield response of orchardgrass to spring sulphur and nitrogen fertilizer applications at Agassiz, BC.

Cut date	Sulphur rate	Nitrogen rate (kg/ha)			
	kg/ha	0	67	134	Mean
		t/ha dry matter			
May 25	0	1.35 d[z]	1.59 cd	1.75 c	1.56 B[z]
	13	1.67 cd	2.63 b	3.19 a	2.50 A
July 5	0	1.47 b	2.20 a	2.25 a	1.97 A
	13	1.73 b	2.11 a	2.37 a	2.07 A
Sept. 23	0	1.50 b	1.36 bc	1.08 d	1.31 B
	13	1.76 a	1.52 b	1.24 cd	1.51 A

[z] Main effect means followed by the same upper case letter, and simple means followed by the same lower case letter (within a Cut Date) were not significantly different (P>0.05). (to convert kg/ha to lb/ac multiply by 0.9; for t/ha to T/ac multiply by 0.45)

Table 4. Comparison of the concentration (ppm) of sulphur extracted by original and revised (1985) BC soil tests in relation to the rating of the soil for crop growth.

Rating	$CaCl_2$	Kelowna
Very low		0-10
Low	<3	11-20
Medium	3-6	21-25
High	>6	26-35
Very high		>35

reduction with hydriodic acid. The barium method is fairly simple and can be automated, but has limited sensitivity (it is pseudo-colorimetric) and subject to interferences from soil constituents and the chemical extracting solutions. The hydriodic acid method is relatively free of interferences and potentially quite sensitive, but it is complex, expensive and difficult to automate. The hydriodic method, unlike the barium method, measures both organically bound and inorganic sulphate anions, which complicates interpretations since the relative availability of organically bound sulphate has not been derived. In contrast, the Inductively Coupled Plasma Spectrometry method measures all forms of inorganic and organic S and is therefore likely to report higher values than the hydriodic acid method. Carbon-bonded S may decompose less easily than organic sulphate so may be less available to plants. With ion chromatography that measures only inorganic (anionic) sulphate, we have shown that a substantial amount of organic S is extracted by Kelowna and other soil test solutions (Kowalenko 2008).

Other S issues and remaining challenges

More S response studies are needed for a wide variety of soils, crops and climates in BC. The following are particular issues we have uncovered.

- Our work has shown that the term 'binding' may more accurately reflect behaviour of inorganic sulphate in acidic coastal soils than the term 'adsorption' (Kowalenko 2005). Binding of sulphate in coastal soils limits leaching despite the wet environment, and keeps fertilizer sulphate available over several growing seasons.
- We have found that fertilizers containing S in the sulphate form (e.g. gypsum) provide readily available S for crop uptake while elemental S requires oxidation to sulphate before it becomes soluble and available to plants (Kowalenko 2004, 2009a, b). While all the soils we tested have microorganisms that oxidize S, the process delays availability.
- Luxury consumption of S by grasses makes it difficult to determine the S status (deficient, adequate or excessive) using plant tissue analyses.
- Sulphur concentration in forages affects the nutritional value of the crop to livestock due to its role in proteins. Conversely, excessive amounts of S in feed may be detrimental to livestock (Boila et al. 1987).
- Many other issues remain unclear such as the role of S in N fixation by legumes, the relative value of S in manure and other organic amendments, the contribution of S in precipitation, and implications of soils with naturally large quantities of sulphate (e.g. gypsum and Epsom salts) in surface and subsurface horizons.

References available online at www.farmwest.com

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