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Review

Sulfur management for rapeseed

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ABSTRACT

Canola or rapeseed (*Brassica* sp. L.) is a major oilseed, being grown on more than 31 million hectares worldwide. Rapeseed has a high concentration of S in its tissue and seed and a particularly high demand for S relative to its yield potential. Therefore, effective S management is an important part of rapeseed production. Sulfur deficiencies are becoming increasingly prevalent due to higher crop yields, decreasing aerial deposition of S and decreasing mineralization of S from soil organic matter. Seed yields of both open-pollinated and hybrid rapeseed are usually optimized with applications of 15–60 kg S ha^{-1} applied as sulfate, which can be applied effectively in the autumn or in the spring, and broadcast, banded or seed-placed, depending on the environment in which the crop is being grown. On coarse-textured soils in high-moisture areas, leaching of autumn-applied sulfate–S may reduce yield response as compared to spring-application. If deficiencies are observed during the growing season, application of sulfate–S as late as bolting to early flowering can be beneficial although yield will generally be lower than if the S had been available from the start of crop growth. Elemental S fertilizers need to oxidize to sulfate before they are available for crop uptake or leaching and will generally not supply sufficient available S to optimize rapeseed yield in the year of application, or possibly for several years, depending on the environmental conditions and the management practices used. Elemental S should be managed in a manner that increases particle dispersion and contact with soil microorganisms to hasten the oxidation process. Management of S fertilizer sources should consider both the short- and long-term impacts on crop yield, seed quality and economics of production. Soil testing to determine the requirements for S fertilizer is challenging due to the spatial and temporal variability in sulfate availability. Improved assessment of S availability needs to consider both the release of S from organic matter and the site-specific distribution of sulfate across the landscape.

Contents

1. Introduction

Canola or rapeseed (*Brassica* sp., primarily *Brassica napus* L. and to a lesser extent *Brassica campestris* L., *Brassica rapa* L. and *Brassica juncea* L.) is one of the major oilseed crops, produced on more than 31 million hectares worldwide (Table 1). China, India and Canada are the major rapeseed-producing countries, with significant areas of production in Europe, Australia, the Russian Federation, and the United States (Table 2). The majority of the rapeseed grown in North America, Europe and Australia and much of the rapeseed grown in the remainder of the world for human consumption is double zero or canola quality, referring to cultivars that have been selected to produce an oil containing less than 2% erucic acid and a solid portion

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Table 1
World area of production (ha) and quantity produced (tonnes) of the top 10 oilseed crops by area, in 2009 (http://faostat.fao.org/site/567/DesktopDefault.aspx?PageID=567#ancor).

Crop	Area of production	Quantity produced
Soybeans	99,501,101	223,184,884
Rapeseed	31,120,565	61,675,518
Seed cotton	30,430,889	60,891,596
Groundnuts, with shell	23,951,156	36,456,791
Sunflower seed	23,716,835	32,391,774
Oil palm fruit	14,921,224	210,326,644
Coconuts	11,864,344	61,708,358
Olives	9,206,504	19,302,675
Sesame seed	7,700,276	3,976,968
Linseed	2,111,538	2,123,649

of the seed containing less than 30 μmol of range of glucosinolates, per gram of air-dry, oil-free solid (Anonymous, 2009a). However, there is a significant amount of rapeseed grown for industrial purposes, such as biodiesel production, and for human consumption, that does not meet the criteria of canola or double zero rapeseed. The remainder of this article will use the term rapeseed to refer to the crop including both canola and rapeseed varieties. Rapeseed has a high protein content with a high proportion of the sulfur (S)-containing amino acids cysteine and methionine (Clandinin, 1986). The tissue of rapeseed also contains high levels of glucosinolates, which are involved in defence systems for certain diseases and insects (Bodnaryk, 1997; Potter et al., 2000; Dubuis et al., 2005). Therefore, rapeseed has a high content of S in the tissue and seed (CFI, 1998; Malhi et al., 2007a) and a particularly great demand for S relative to its yield potential (Jackson, 2000). Rapeseed (*B. campestris* L.) requires from 3 to 10 times more S than barley (Bole and Pittman, 1984) and an adequate supply of S is important to ensure optimum rapeseed yields (Jackson, 2000; Malhi and Leach, 2002).

2. Occurrence of sulfur deficiency in rapeseed

Many of the areas where rapeseed is grown are subject to sulfur deficiencies. In Europe, S deficiencies have been noted in rapeseed crops since the mid-eighties, related to the reduction in atmospheric S deposition that previously provided a significant source of plant-available S (Haneklaus et al., 2008). The risk of deficiency is also relatively high in most of the Northern Great Plains due to the low aerial deposition of S that occurs related to the limited industrialization in the region (http://nadp.sws.uiuc.edu, accessed September 14, 2011). In the United States, slightly over 0.5 million hectares of rapeseed were grown in 2005, with approximately 90% of the production occurring in North Dakota and Minnesota (Anonymous, 2009b). The majority of rapeseed in Canada is grown in the Parkland region of the three Prairie Provinces (Statistics_Canada, 2011) where many agricultural soils are deficient or potentially deficient in plant-available S for high seed yield of rapeseed (Bettany and Stewart, 1983; Doyle and Cowell, 1993). In the Prairie Provinces, there are more than 4 million ha of agricultural soils deficient in plant-available S and substantially greater areas are potentially deficient (Bettany and Stewart, 1983; Doyle & Cowell, 1993).

Occurrence of S deficiency is strongly affected by soil characteristics, being most common on soils that are low in organic matter, where S release by mineralization will be limited, and on coarse-textured soils where the S has leached out from the rooting zone over time (Riley et al., 2002; Franzen and Grant, 2008). Sulfate is released from organic matter through mineralization (Kirchmann et al., 1996), so the risk of S deficiency decreases with higher organic matter content and higher potential mineralization. Sulfur deficiencies in Canada were initially identified on the Gray Luvisolic soils, as these soils are particularly susceptible to S deficiency because they are highly leached soils with a lower organic matter content than the Chernozemic soils that developed under grasses (Nyborg et al., 1974; Ukrainetz et al., 1975; Nuttall et al., 1987). With the increased production of rapeseed, movement to more intensive crop production practices, use of higher yielding cultivars, and decrease in aerial deposition of S due to increased air quality standards, S deficiencies have been identified on a broad range of soils in North America, Europe, Asia and Australia (Karamanos, 1988; Ali et al., 1996; McGrath and Zhao, 1996; Jackson, 2000; Grant et al., 2004; Malhi et al., 2004; Brennan and Bolland, 2006, 2008; Solberg et al., 2007; Haneklaus et al., 2008; Egesel et al., 2009). Producers have experienced substantial decreases in seed yield due to S-deficiency and application of S fertilizer to rapeseed crops is a recommended and widely followed practice (Good and Glendinning, 1998; Thomas, 2003; Haneklaus et al., 2008). For example, over 336,000 metric tonnes of ammonium sulfate were sold in western Canada in 2006 (http://www.cfi.ca/files/publications/statistical_documents/CFI_retail_stats_04-06-30.PDF, accessed September 14, 2011).

3. Sulfur requirements for rapeseed

Sulfur requirements of rapeseed are substantially higher than those of noncruciferous crops (Bole and Pittman, 1984; Bailey, 1986; Good and Glendinning, 1998; Haneklaus, 2006; Haneklaus et al., 2008). While the seed of the low glucosinolate cultivars contain lower S than the older high glucosinolate cultivars, this does not seem to significantly reduce the S requirement of the crops. For example, in studies in England using double low and single low winter oilseed rape cultivars, total S uptake at maturity was similar in the two varieties but more of the S was located in the seed of the single low cultivar, due to its high glucosinolate content (Zhao et al., 1993b). Early studies using open-pollinated rapeseed cultivars indicated that approximately 1.5 kg of S was needed to produce 100 kg of seed yield (Nyborg et al., 1974). The Canadian Fertilizer Institute suggests that a rapeseed crop producing approximately 1960 kg ha^{-1} would require about 20–24 kg S ha^{-1} for growth and would remove about 12–14 kg S ha^{-1} in the harvested seed (CFI, 1998). Field studies conducted over the years across the Canadian prairies determined that yield of rapeseed was generally optimized at rates of application of 15–30 kg S ha^{-1} (Hamm et al., 1973; Nyborg et al., 1974; Nuttall et al., 1987; Riley et al., 2000; Grant et al., 2004; Malhi and Gill, 2006, 2007; Karamanos et al., 2007; Malhi et al., 2007a). In Australia, a 40 kg S ha^{-1} rate of application is recommended for soils testing low in S, whereas a rate of

Table 2
Canola/rapeseed area of production (ha) and quantity produced (tonnes) of the top 15 producing countries in 2009 (http://faostat.fao.org/site/567/DesktopDefault.aspx?PageID=567#ancor).

Country	Are of production	Quantity produced
China	7,278,013	13,657,012
India	6,300,000	7,201,000
Canada	6,104,500	11,825,400
France	1,480,810	5,588,730
Germany	1,471,200	6,306,700
Australia	1,394,000	1,910,000
Ukraine	1,013,700	1,873,300
Poland	809,970	2,496,830
United Kingdom	581,000	1,951,000
Russian Federation	556,300	666,840
Romania	414,285	569,611
Czech Republic	354,826	1,128,120
Belarus	340,315	610,968
United States of America	329,780	669,340
Hungary	260,608	579,365