Research Findings

Rapeseed fields in France. Photo by P. Dugast.

Use of Polyhalite as a Source of Sulfur for Oilseed Rape and Winter Wheat in France

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Abstract

Polysulphate™ (Cleveland Potash Ltd., UK) is the trade mark of the natural mineral 'polyhalite', which occurs in sedimentary marine evaporates, consisting of K_2O: 14%, SO_3: 48%, MgO: 6%, CaO: 17%. Sulfur (S) deficiency has been recognized as a limiting factor for crop production in many regions in the world, particularly in Brassica and cereal crops. The objective of the present study was to assess the performance of common arable crops - oilseed rape (*Brassica napus* L.) and winter wheat (*Triticum aestivum*) under polyhalite fertilizer in comparison with commonly-used S fertilizers. Experiments were carried out in 2013 and 2014, in two locations in north-east France, typified by silty-loam and shallow calcareous soils, respectively. Supplemental S gave rise to a significant yield increase in oilseed rape, particularly on shallow calcareous soils. However, S impact on winter wheat yields in the present study was negligible, probably due to adequate S

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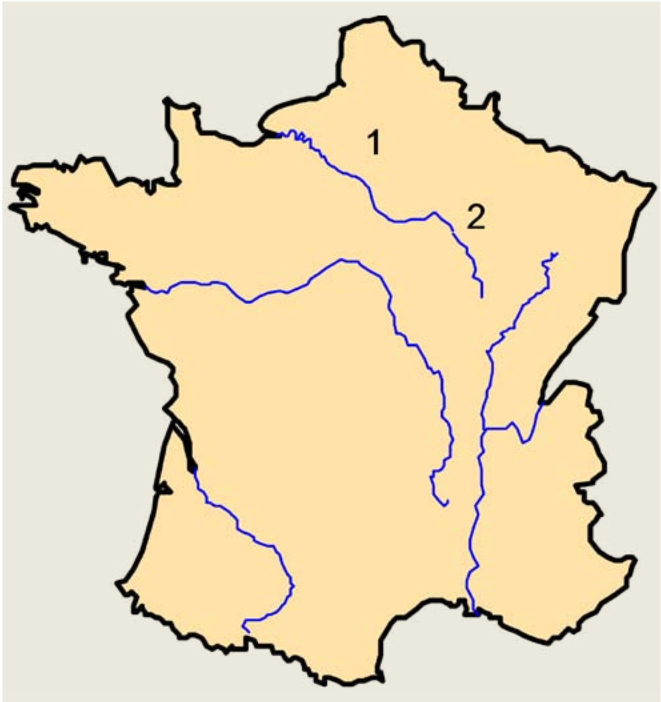
availability in the soil. Polyhalite performance was equivalent to those of well-established S fertilizers; further economic evaluations are therefore necessary.

Introduction

Sulfur (S) is increasingly being recognized as the fourth major plant nutrient after nitrogen (N), phosphorus (P), and potassium (K) (Khan *et al.*, 2005). Sulfur deficiency has also been recognized as a limiting factor for crop production in many regions worldwide. In particular, S deficiency incidence has increasingly been reported in Brassica and cereal crops in Western Europe during the 1990s, mainly as a consequence of a massive decrease in atmospheric S inputs as industrial pollution (which resulted in S inputs to the soil as acid rain) reduced under tighter regulations (Zhao *et al.*, 1999). Sulfur is a constituent of amino acids cysteine and methionine, which act as a precursor for the synthesis of proteins and other compounds containing reduced S (Marschner, 1995). Several studies have established regulatory interactions between N and S assimilation in plants (Kopriva *et al.*, 2002). Sulfur availability regulates N utilization efficiency in plants, and thus affects photosynthesis, growth, and dry mass accumulation in crops.

Winter wheat (*Triticum aestivum*) is a major arable crop, for which application of available sulfur is beneficial to achieve high yields (Randall *et al.*, 1981; Zhao *et al.*, 1999; Hoel, 2011; Järvan *et al.*, 2012; Kulhánek *et al.*, 2014), even if visual deficiencies are not even detected. Wheat's S requirement is about 15–20 kg ha^{-1} for optimum growth (Zhao *et al.*, 1999). Reproductive growth of wheat appears to be more sensitive to S deficiency than vegetative growth (Steinfurth *et al.*, 2012), resulting in decreased grain size under S-limiting conditions (Zhao *et al.*, 1999). In addition to impact on yields, the S status of wheat grain is an important parameter for the quality of wheat products (Moss *et al.*, 1981). Limiting S availability has been shown to favor the synthesis and accumulation of S-poor or low-S storage proteins, such as ω-gliadin and high molecular weight subunits of glutenin at the expense of S-rich proteins (Steinfurth *et al.*, 2012; Dai *et al.*, 2015). Sulfur deficiency also decreases the proportion of polymeric proteins in total proteins, but shifts the distribution of polymeric proteins toward lower molecular weight (Wrigley *et al.*, 1984). These changes in the protein composition results in alterations in dough physical properties, which impact on bread-making quality. A significant link between bread-making quality and the addition of S fertilizers has been established under field conditions (MacRitchie and Gupta, 1993; Zhao *et al.*, 1999).

Sulfur is often associated with crops belonging to the Brassicaceae family. The Brassicaceae include several oilseed crops, among which canola (rapeseed or oilseed rape, *Brassica napus* L.) has become very important, economically. Sulfur and N fertilization, and the balance between them, have a prominent



Map 1. Map of France, with the two experimental sites: 1. Deep silty-loam soil. 2. Shallow calcareous soil.

effect on glucosinolate concentration in brassicaceous plants and an increased S supply has been shown to result in higher levels of total glucosinolates (Li *et al.*, 2007). Sulfur deficiency was shown to increase the disease susceptibility of canola to various fungal pathogens (Dubuis *et al.*, 2005) and this loss of anti-fungal activity was strongly correlated with the reduction of various glucosinolates, suggesting that they could have antimicrobial potential. An increase in S fertilization has also been shown to affect polyphenol content e.g. flavonoids and phenolic acids (De Pascale *et al.*, 2007). Zhao *et al.* (1993) showed that supplemental S had brought about considerable increase in oilseed rape yield.

Sulfur is readily available to plants only in its inorganic form as sulfate (SO_4^{2-}). Organic and elemental S must be converted into the inorganic form through microbial activity, a process depending on the soil C:S ratio, temperature, and moisture (Boswell and Friesen, 1993). Sulfate, as a negatively charged ion, is extremely mobile in the soil and is often leached from the root zone. Therefore, significant efforts are made to slow the sulfate release rate to the soil (e.g. using granulation, which increases energy inputs and production costs).

Polysulphate™ (Cleveland Potash Ltd., UK) is the trade mark of the natural mineral 'polyhalite', which occurs in sedimentary marine evaporates, consisting of a hydrated sulfate of K, calcium (Ca) and magnesium (Mg) with the formula: $K_2Ca_2Mg(SO_4)_4·2(H_2O)$.

The deposits found in Yorkshire in the UK typically consist of K_2O: 14%; SO_3: 48%; MgO: 6%; and CaO: 17%. As a fertilizer comprising four key plant nutrients - S, K, Mg, and Ca - polyhalite may provide new approaches for crop nutrition. In polyhalite, S is progressively available; 50% is immediately available, and the rest is slowly released later on. Thus, the objective of the present study was to assess the performance of common arable crops - oilseed rape and winter wheat - under polyhalite fertilizer in comparison with commonly used S fertilizers.

Materials and methods

Trials were carried out for wheat and rapeseed at two experimental sites in north-east France, significantly differing in their soil properties (Map 1): 1. Catenoy, Oise, Picardie, typified by deep silty-loam soil (2013); and, 2. Rochetaillée (rapeseed) and Mouchy-le-Châtel (wheat), Haute Marne, Champagne-Ardenne (2014), with shallow calcareous soils.

Oilseed rape

In both experiments, polyhalite was compared to the soluble S reference magnesium sulphate (Mag25™: $MgSO_4$, 9.8% Mg, 12.3% S). Both sulfur fertilizers were applied to provide 30 or 28 g S ha^{-1}, in site 1 or 2, respectively. In 2013, polyhalite was applied at the C_1 stage of development (Joosen *et al.*, 2007), whereas the reference $MgSO_4$ was applied 15 days later, at the C_2 stage. In 2014, S application was tested at each of the evelopmental stages (Table 1). Nitrogen, P, K, and Mg were applied to provide non-limiting, balanced conditions. Trials were executed under a 3-replicate protocol. Yields (Mg ha^{-1}) are presented as grain dry matter at 9% standard humidity.

Winter wheat

In 2013, granulated ammonium nitrate (AN) containing sulphate (NS: 26% N; 13% S) was employed as the S reference fertilizer (20 kg S ha^{-1}). Polysulphate™ (20 kg S ha^{-1}) was applied at tillering simultaneously with N, using ammonium nitrate at a complementary level.

In 2014, S was provided at 25 kg ha^{-1} in both polyhalite and the S reference fertilizer, the latter consisting of magnesium sulphate. Nitrogen fertilization was based on urea ammonium nitrate (UAN), applied simultaneously with S at the five tiller stage. Phosphorus, K, and Mg were applied to provide non-limiting, balanced conditions. A detailed description is given in Table 2.

Table 1. Detailed description of the oilseed rape trials.

	Treatment	Code	N	SO_3	Date of S
			-------*kg ha^{-1}*-------		
			(UAN)		
2013 (Silty-loam soil)	Non-fertilized control	NFC	0	0	
	Nitrogen	NS_0	210	0	
	Nitrogen+Polysulphate™	NPS	210	72	27/02
	Nitrogen+Mag25™	Ref. S	210	72	20/03
2014 (Shallow calcareous soil)	Nitrogen	NS_0		0	
	Nitrogen+Polysulphate™ C_1	NPS C_1	180	70	24/02
	Nitrogen+Mag25™ C_1	Ref. S C_1	180	70	24/02
	Nitrogen+Polysulphate™ C_2	NPS C_2	180	70	17/03
	Nitrogen+Mag25™ C_2	Ref. S C_2	180	70	17/03

Note: UAN = Urea Ammonium Nitrate

Table 2. Detailed description of the winter wheat trials.

	Treatment	Code	N	SO_3	Date of S
			-------*kg ha^{-1}*-------		
			(AN)		
2013 (Silty-loam soils)	Nitrogen	NS_0	210	0	
	Nitrogen+Polysulphate™	NPS	210	50	28/02
	Nitrogen+S	Ref. S	210	50	28/02
			(UAN)		
2014 (Shallow calcareous soils)	Non-fertilized control	NFC	0	0	
	Nitrogen	NS_0	180	0	
	Nitrogen+Polysulphate™	NPS	180	62	04/03
	Nitrogen+Mag25™	Ref. S	180	62	04/03

Note: AN = Ammonium Nitrate; UAN = Urea Ammonium Nitrate

Yields (Mg ha^{-1}) are presented as grain dry matter at 15.5% standard humidity. Protein content is expressed as the percentage of grain weight at the 15.5% standard humidity.

Results and discussion

Oilseed rape

Large yield differences occurred between the fertile silty-loam soil (2013), where very high yields (2.9 Mg ha^{-1}) were obtained without any nitrogen supplements, and the poor, shallow calcareous soil (2014), where the highest yield levels did not reach 2.6 Mg ha^{-1}, even under the full fertilization regime (Fig. 1). Excluding differences in weather conditions between the two years or sites, the principal differences occurred in yield levels can be attributed to a certain inability of the shallow soils of Haute Marne region to withhold and provide adequate water for the crop (Fismes *et al.*, 2000). Oilseed rape yield is very sensitive to water deficiency, particularly at the stages of floral development, fruit set, and seed filling (Bouchereau *et al.*, 1996; Champolivier and Merrien, 1996; Wright *et al.*, 1996).

Nitrogen, when applied solely (NFC) to the rich soil of Catenoy, brought about a significant increase of almost 50% in yield. Oilseed rape is an N-inefficient crop, which always, though gradually, responds to additional N supply (Fismes *et al.*, 2000; Rathke *et al.*, 2006). In both experiments, S supplements tended to increase yield (Fig. 1), however, the response was much more significant in the shallow calcareous soil at Rochetaillée, Haute Marne. Whereas only 0.45 Mg ha^{-1} (about 10%) was added to the yield at the rich soil of Catenoy, the yield was almost doubled in response to S fertilization at Rochetaillée.

These results demonstrate again the significance of S fertilization to Brassicaceae crops and the synergistic relationships between N and S, whenever available in the soil (Zhao *et al.*, 1993; McGrath and Zhao, 1996; Fismes *et al.*, 2000; Li *et al.*, 2007). The dramatic effect obtained in the shallow soils at Haute Marne may be explained by the fact that S is often leached out of the soil top layer, thus S application might significantly raise its availability to the crop.

The differences in yield between the two S sources did not provide any statistical significance, nor did their application at different stages of plant development. Other studies also show that when optimizing application date, polyhalite efficiency is perfectly similar to that of magnesium sulfate (unpublished data).

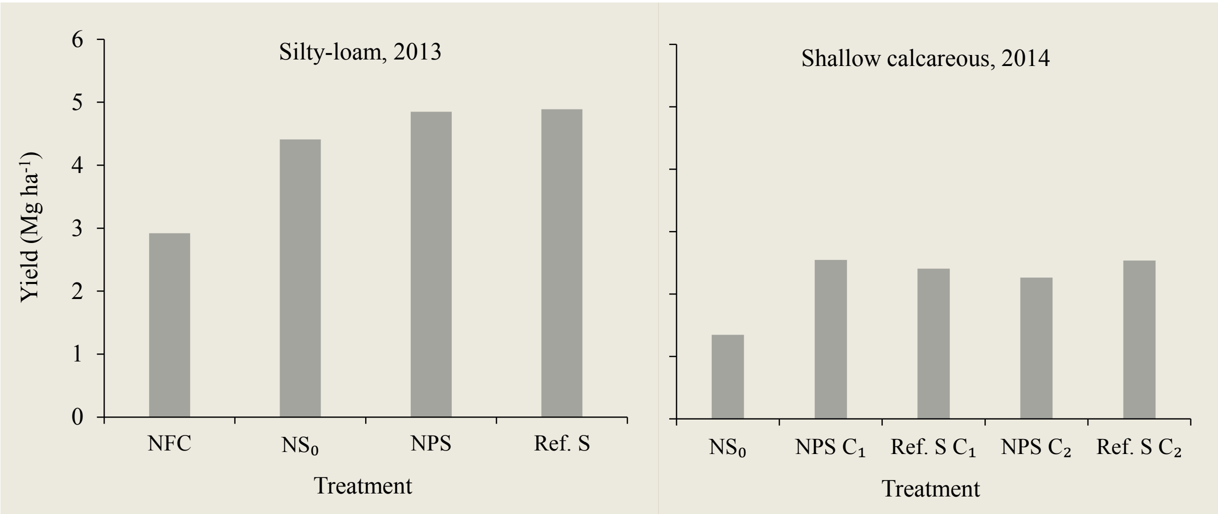


Fig. 1. Oilseed rape yields, expressed in standard terms of dry tonne per hectare (Mg ha^{-1}), as affected by two sulfur sources, Polyhalite or $MgSO_4$. NFC: non-fertilized control; NS_0: fertilized with N alone; NPS: N + polyhalite. Nitrogen and/or S were applied during stages C_1 and C_2 of rapeseed development. In 2013, CV (covariance) and MSE (mean standard error) were 4.6% and 0.2 Mg ha^{-1}, respectively; in 2014, CV was 10%.

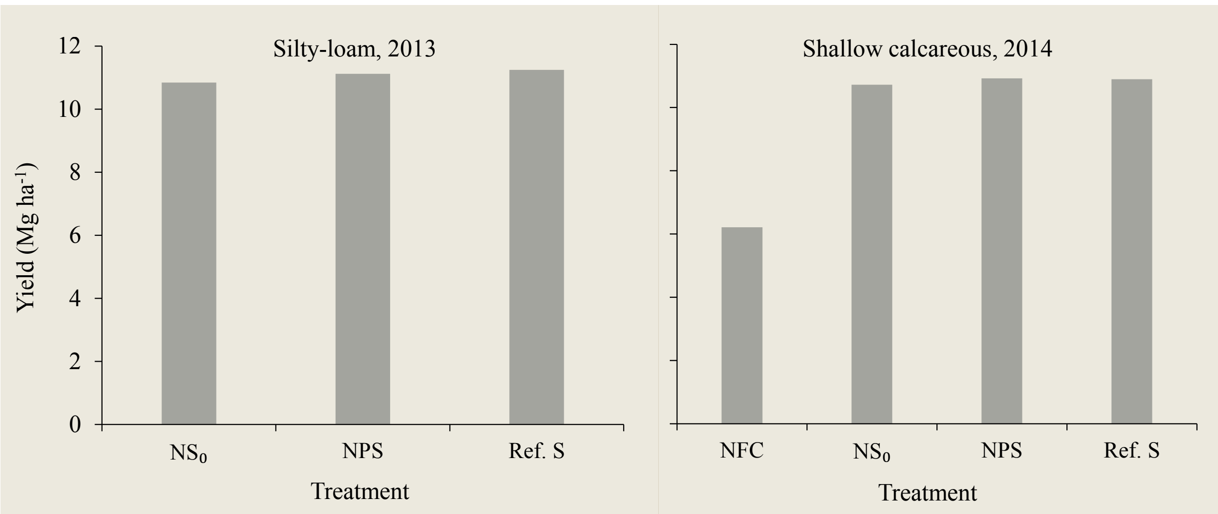


Fig. 2. Winter wheat yields, expressed in standard terms of dry tonne per hectare (Mg ha^{-1}), as affected by two sulfur sources, polyhalite vs. S reference fertilizer (NS in 2013 or $MgSO_4$ in 2014). NFC: non-fertilized control; NS_0: fertilized with N alone; NPS: N + Polyhalite. CV was 2.9% and 2%, in 2013 and 2014, respectively.

Winter wheat

On the fertile silty-loam soil (2013), and with a background of regular N application, the supplemental S slightly increased winter wheat yield by 0.3-0.4 Mg ha^{-1}, which was statistically insignificant (at a significance level of 5%) (Fig. 2). Grain protein content did not respond to the S supplement, remaining constant at 11.3-11.5%. On the shallow calcareous soil (2014), the contribution of N fertilizer alone was responsible for about 89% rise in grain yield, and to an upsurge in protein content from 9.3 to 10.6%. Nevertheless, the S supplement had negligible influences on yield and grain protein content. In both winter wheat experiments, no differences occurred between polyhalite and the S reference fertilizers, magnesium sulphate or AN containing sulphate, in regard to their effects on yield (Fig. 2).

The absence of a significant influence of S application on winter wheat yields in the present study is not surprising. In spite of the general proven effects of S fertilizers on wheat yield, it has been clearly stated that these might be strongly dependent on local or temporal, edaphic or climatic conditions, respectively (Hoel, 2011; Järvan *et al*., 2012; Kulhánek *et al*., 2014). In all these studies, S effects on winter wheat yields were inconsistent, occurring in certain years or locations but absent in others. Considering the high yields obtained, it may well be that the initial S status in the soil, in both sites, was enough to provide all crop requirements of winter wheat, so S supplement in these cases was ineffective. Unfortunately, some impacts that S fertilizers might have had on the grain and flour quality were beyond the scope of the present study and, therefore, were not examined.

Conclusions

The significance of S application to oilseed rape yield is demonstrated, particularly on shallow calcareous soils. Unfortunately, similar influences were not shown in this study for winter wheat, probably due to adequate S availability in the soil. Polyhalite performance was equivalent to those of well-established S fertilizers, and therefore, remains to be further evaluated at the economical level.

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The paper "Use of Polyhalite as a Source of Sulfur for Oilseed Rape and Winter Wheat in France" also appears on the IPI website at:

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