

Phosphorus, Potassium and Sulphur Nutrition of Red Clover (*Trifolium pratense* L.) Seed Crops

Trygve Sveen Aamlid¹

ABSTRACT

Mineral fertilizers containing phosphorus (P), potassium (K) and/or sulphur (S) were applied in spring to seven seed crops of red clover (*Trifolium pratense* L.) on marine clay soils in SE Norway during 1994-1996. With the exception of one crop in which application of potassium sulphate (200 kg ha⁻¹) gave a higher seed yield than application of superphosphate P9 (300 kg ha⁻¹) or complex HYDRO-PKTM 7-18 (300 kg ha⁻¹), fertilizer inputs had no effect on seed yield or thousand seed weight. Although superphosphate increased plant P concentration and gypsum tended to elevate plant S concentration, plant nutrient uptake was more influenced by initial soil fertility, as indicated by test values for ignition loss, P and K in the topsoil (0-20 cm) and subsoil (20-40 cm), than by mineral inputs. Potassium sulphate reduced the hard seed content in one out of seven crops. In conclusion there seems to be little need for fertilizer inputs for red clover seed production on marine clay soils in SE Norway.

Additional index words: gypsum, hard seeds, phosphorus, plant analyses, potassium, red clover, seed production, soil analyses, sulphur, *Trifolium pratense*

INTRODUCTION

Three to seven hundred hectares of red clover (*Trifolium pratense* L.) seed are harvested in Norway annually. Production is carried out in the southeastern part of the country, mostly on marine soils with 10-35 % clay. The seed crops are established at sowing rates ranging from 1 to 6 kg ha⁻¹ using spring grain cover crops, and they are usually harvested for only one year, or a maximum of two years if there is shortage of seed. During the period 1990-97, Norwegian seed yields averaged 240 and 460 kg ha⁻¹ for tetraploid and diploid cultivars, respectively.

Like other legumes, red clover provides its own nitrogen (N) by symbiosis with N-fixing bacteria. The need for fertilizer inputs of other nutrients such as phosphorus (P), potassium (K), sulphur (S), calcium (Ca), magnesium (Mg) and, among the micronutrients most importantly boron (B) and molybdenum (Mo) (Clifford and Rolston, 1990), varies with soil type. While there are many reports (e.g. Antoniv, 1985; Craiu, 1987; Kalikinskii and Persikova, 1992) showing seed yield increases from moderate inputs of P and K to red clover seed crops, it is well recognized that excessive or unbalanced applications of these and other elements may be more detrimental in the production of seed than in the production of forage. The latter can be illustrated by two examples, both admittedly from white clover (*Trifolium repens* L.); one in which seed yields were higher with 10 than with 0 or 30 kg P ha⁻¹ (Clifford and Rolston, 1990), and the other in which 100 kg K ha⁻¹ produced more seed than 0 or 200 kg K ha⁻¹ (Nordestgaard, 1986). Among the negative effects of excessive K inputs to red clover seed crops are less flower heads per plant, reduced nectar secretion per flower head, and lower sugar concentration of plant nectar (Sheul, 1957).

During the last decade, plant nutrition research in Norway has focused on S more than on P and K. Since 1980, cleaner emissions from the industry and transport sector, both in Norway and in England, Germany, Poland and other countries from which wind directions prevail, have reduced the average annual precipitation of atmospheric S to south-

Norwegian soils from 13 to 5 kg ha⁻¹ (Stabbetorp and Myhr, 1994). During the same period, increasing soil test P values led many farmers to apply N or NK fertilizers which did not contain S. For these and other reasons, recent experiments showed up to 400 % seed yield increases from application of 17-30 kg S ha⁻¹ to spring turnip rape (*Brassica campestris* spp. *oleifera*) on light soils in areas with low summer temperatures (Repstad and Stabbetorp, 1996). The seed yield increases were far less conspicuous, (on average 4-5%), for wheat, barley and oats in areas with higher summer temperatures and thus more mineralization of S from soil organic matter. On marine clay soils in SE Norway, i.e. where most of the red clover seed is also grown, cereals often showed no response to S at all (Repstad and Stabbetorp, 1996; Repstad, Rudd and Stabbetorp, 1997). However, since legumes normally have a higher concentration of S in plant dry matter, it is usually assumed that they require more S than cereals, although their requirement is not nearly as high as in spring turnip rape or other cruciferous crops (Ødelien, 1966; Mengel and Kirkby, 1987). Clifford and Rolston (1990) reported that application of 20 kg S ha⁻¹ as either gypsum or superphosphate increased seed yields of white clover by 50% on a soil that had been depleted for S during many years of cereal cropping with irrigation and input of only N and P.

Norwegian growers have always been advised to apply P and K to their red clover seed crops. This has never been verified experimentally, and the S nutrition of such crops has received little attention. The objective of the present research was to evaluate the need for fertilizer inputs, particularly of S, but also of P and K, to red clover seed crops in SE Norway.

MATERIALS AND METHODS

Five on-farm trials were laid out in red clover seed crops in spring; three trials in 1994 and one trial in each of the years 1995 and 1996 (Fig. 1). All seed crops had been undersown the previous year in a spring cereal (oats, barley or wheat); the one in Våle at a sowing rate of approximately 1 kg ha⁻¹ and 50 cm row spacing; the others at higher sowing rates (3-7 kg ha⁻¹)

¹ The Norwegian Crop Research Institute, Division Landvik, N-4890 Grimstad, Norway. Accepted for publication 14 December 1998.

and 11-15 cm row spacings. Soil types varied from silt loams to silty clay loams; initial soil test values are given in Table 1. Total soil S was determined by extraction with $Mg(NO_3)_2$ followed by complete combustion of organic matter, suspension of the ash in HCl, precipitation of SO_4 with $BaCl_2$ and finally turbidimetric analysis of the $BaSO_4$ precipitate at 450 nm (Johnson and Fixen, 1990). Information about extraction methods for P and K has been provided by Aamlid (1998a).

The experimental treatments were as indicated in Table 2. Each trial had three replicates. Fertilizer was applied at the start of growth in late April or early May. Details about cultivars, application dates, plant density, weed control and seed harvest are given in Table 3.

(ISTA, 1996). Experimental data from each crop were subjected to analyses of variance (PROC ANOVA; SAS (1990)). In the final overall analyses, each crop was considered as one replicate.

RESULTS

In the first year crop at Våle in 1994, seed yield was significantly higher from plots which had received K+S than from plots which had received P+S or P+K+S (Table 4). No effect of fertilizers could be detected in any other crop or on average for all crops. Seed yields of the tetraploid cultivar

Table 1. Initial soil test values for the 0-20 and 20-40 cm soil layers in the experimental fields.

Site	Loss on ignition, % ¹	pH (H ₂ O)	mg (100 g dry soil) ⁻¹			
			P-AL ²	K-AL ²	K-HNO ₃ ²	Total-S
Våle						
0-20 cm	4.2	6.1	3.5 (II)	10.7 (II)	109 (III)	13.1
20-40 cm	2.7	6.0	2.8 (I)	7.9 (II)	115 (III)	10.0
Gvarv						
0-20 cm	7.5	6.3	6.0 (II)	32.3 (IV)	157 (IV)	31.8
20-40 cm	6.1	6.4	4.5 (II)	24.9 (III)	162 (IV)	20.7
Hokksund						
0-20 cm	6.7	6.1	7.5 (III)	11.4 (II)	148 (IV)	39.3
20-40 cm	3.3	6.5	4.0 (II)	6.1 (I)	172 (IV)	17.8
Skotselv						
0-20 cm	6.8	6.1	5.9 (II)	18.7 (III)	105 (III)	32.5
20-40 cm	4.2	5.7	3.4 (II)	9.3 (II)	109 (III)	17.7
Ørje						
0-20 cm	6.1	6.0	7.3 (III)	15.6 (III)	151 (IV)	14.7
20-40 cm	4.5	6.1	4.6 (II)	15.8 (III)	175 (IV)	10.4

¹ Loss on ignition has not been corrected for clay content.

² Roman numerals in parentheses after P-AL, K-AL, K-HNO₃ values refer to a Norwegian classification system for these nutrients: I=Low, II=Medium, III=High, IV=Very high. The system does not include S.

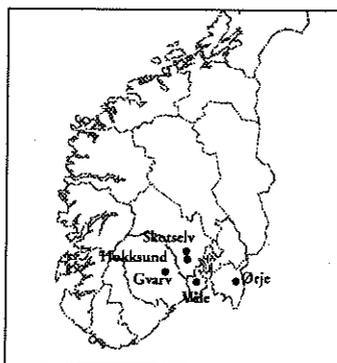


Figure 1. Map of south Norway showing experimental sites.

In all trials a one plant sample per treatment (common for three replicates) was taken in June (see Table 3 for sampling dates). These samples were frozen and later analyzed for P, K and S. Too little plant material prevented analyses of S in one sample.

The crops were desiccated with diquat (400-600 g a.i.ha⁻¹) when approximately 70% of the flower heads were ripe and

combined with Wintersteiger Nurserymaster field plot combines. Gross plot size was 1.6 m x 8.0 m, of which 1.45 m x 6.6 m was harvested for seed. The trials in Våle and Gvarv were harvested in two consecutive years; the remaining only in the first seed production year.

The seed lots from all plots in all experiments were cleaned and analyzed for purity, thousand seed weight and germination in accordance with internationally agreed methodology

Kolpo at Våle were generally much lower than of the diploid cultivar Bjursele at the other sites.

Fertilizer inputs did not affect thousand seed weight in any of the crops (data not provided). Average thousand seed weights (14 % moisture content) for cvs. Kolpo and Bjursele were 2947 and 2009 mg, respectively.

Seed germination was significantly influenced by fertilizer treatments in the second year crop at Gvarv in 1995 (Table 5). The number of hard seeds was higher, and the number of normal seedlings correspondingly lower, on unfertilized control plots than on plots which had received K+S; the other treatments ranked between these extremes. However, on average for all crops germination was not affected by fertilizer applications.

The concentration of P in plant dry matter in June (i.e. before flowering) was significantly higher on plots which had received P (treatments 3 and 5) than on plots which had had no such input (Table 6). The concentration of K and S in plant dry matter was not significantly affected by treatments, although there tended to be less S in the dry matter on unfertilized control plots. The concentrations of P, K and S in red clover dry matter in June were highly

Table 2. Fertilizers treatments and corresponding inputs of pure nutrients in experiments with application of P, K, and S to red clover seed crops.

Treatment, no	Type of fertilizer	Rate, kg ha ⁻¹					
		Fertilizer	P	K	S	Ca	Mg
1	Control: No fertilizer	-	-	-	-	-	-
2	Gypsum, CaSO ₄ · 2 H ₂ O	194	-	-	36	45	-
3	Superphosphate, P9	300	23	-	36	72	-
4	Potassiumsulphate, K ₂ SO ₄	200	-	82	36	-	-
5	HYDRO-PK TM 7-18	300	22	55	17	21	7.2

Table 3. Cultivar, calendar year, seed harvest year, plant density in spring, date of fertilizer input, date of sampling for plant analyses, weed control data, date of desiccation and date of seed harvest in experiments with application of P, K and S to red cover seed crops.

Location	Cultivar (Ploidy)	Calendar year	Seed harvest year	Density in spring, plants m ⁻²	Fertilizer input, date	Plant sampling, date
Våle	Kolpo (4x)	1994	1	6.8	28 Apr	1 Jun
		1995	2	9.3	25 Apr	-
Gvarv	Bjurselse (2x)	1994	1	32	5 May	-
		1995	2	14	10 May	16 Jun
Hokksund	Bjurselse (2x)	1994	1	-	2 May	3 Jun
Skotselv	Bjurselse (2x)	1995	1	61	11 May	13 Jun
Ørje	Bjurselse (2x)	1996	1	65	7 May	27 Jun

Location	Weed control		Desiccation with diquat, date	Seed harvest, date
	Spraying, date	Herbicide Rate, g a.i. ha ⁻¹		
Våle		no weed control	20 Aug	1 Sep
		no weed control	16 Sep	22 Sep
Gvarv	1 May	bentazone 1440	15 Aug	30 Aug
	25 Jun	sethoxydim 660	25 Aug	19 Sep
Hokksund	2 May	bentazone 1440	23 Aug	1 Sep
Skotselv		no weed control	12 Sep	22 Sep
Ørje		no weed control	6 Sep	17 Sep

correlated (Table 7), the samples from Gvarv ranking highest and those from Våle lowest for all three elements.

The concentrations of P and K in plant dry matter from unfertilized control plots were significantly correlated with initial soil test values. While the P concentration was more strongly related to P-AL in the 20-40 cm subsoil than in the 0-20 cm topsoil (Fig. 2), plant K showed a stronger relationship to topsoil than to subsoil values for either K-AL (data not shown) or K-HNO₃ (Fig. 3). Among the two K-indices, plant K was slightly better correlated with K-HNO₃ than with K-AL ($r=0.81$ vs. $r=0.75$ for the topsoil layer). Plant S concentration from unfertilized plots showed stronger correlations with ignition losses in both soil layers (Fig. 4) than with total soil S in either topsoil ($r=0.47$) or subsoil ($r=0.68$).

DISCUSSION

On average for seven harvests, there was no effect of P, K or S on red clover seed yields on clay soils in SE Norway. The results for S are in good agreement with Bærug (1977) and

Repstad *et al.* (1997) who found little or no response to S in field experiments with grasses and cereals on similar soils. In contrast, application of gypsum (corresponding to 60 kg S ha⁻¹) increased yields of barley by 36% and dry matter yields of red clover by 30% in the first cut and 136% in the second cut in a pot experiment with marine clay soils that had not received S for a 10 year cropping period (Uhlen and Bærug, 1984). Apart from the fact that it is common to find greater responses to S in indoor pot experiments than in outdoor field experiments with the same soils (Uhlen and Bærug, 1984; Johnson and Fixen, 1990), the latter data suggest that most S is taken up during vegetative growth (Horneck, Hart and Young, 1993) and that the need for S application on marine clay soils is not greater in red clover seed crops than in cereals or single-cut grasses.

Attempts to define S concentrations in the dry matter of various clover species below which deficits occur have arrived at values ranging from 0.14 to 0.26 % (Spencer, 1978; Bansal and Pal, 1987; Turker and Dikshit, 1994). The data presented in Table 6 are not outside this range, and there is no evidence that the concentration of S in red clover tissue was suboptimal for either vegetative growth or seed production. Besides the

Table 4. Effects of fertilizer inputs on seed yields (kg ha⁻¹)¹ of seven red clover seed crops.

Treatment no: Nutrient applied ²	Våle 1994	Våle 1995	Gvarv 1994	Gvarv 1995	Hokksund 1994	Skotselv 1995	Ørje 1996	Mean
1: None (control)	94	147	900	361	708	480	211	414
2: S	92	130	879	372	730	464	218	412
3: P + S	76	135	872	345	703	460	207	400
4: K + S	107	164	951	335	714	504	180	422
5: P+K+S	86	131	862	309	723	545	181	405
P-value	<0.05	>0.2	>0.2	>0.2	>0.2	>0.2	>0.2	>0.2
LSD _{P<0.05}	16	³	-	-	-	-	-	-

¹ 100% purity, 14% moisture content

² See Table 2 for information about nutrient rates.

³ No significant difference.

Table 5. Effects of fertilizer inputs on per cent normal seedlings and per cent hard seeds after incubation for 10 days at 20°C of seed from various fertilizer treatments at Gvarv in 1995 and on average for seven red clover seed crops.

Treatment no: Nutrient applied ¹	Normal seedlings, %		Hard seeds, %	
	Gvarv 1995	Mean of 7 crops	Gvarv 1995	Mean of 7 crops
1: Control	49	79	42	16
2: S	57	78	37	16
3: P + S	54	77	39	17
4: K + S	64	80	30	15
5: P+K+S	54	77	41	17
P-value	<0.001	>0.2	<0.01	>0.2
LSD _{P<0.05}	4	-	4	-

¹ See Table 2 for information about nutrient rates.

Table 6. Concentration of P, K and S in red clover dry matter in June (before flowering) as affected by fertilizer treatments. Average of 6 crops for S and 7 crops for K and P.

Treatment no: Nutrient applied ¹	Concentration, % of dry matter		
	P	K	S
1: Control	0.22	2.6	0.16
2: S	0.22	2.5	0.18
3: P + S	0.26	2.3	0.18
4: K + S	0.23	2.7	0.17
5: P+K+S	0.25	2.6	0.18
P-value	<0.001	>0.2	0.10
LSD _{P<0.05}	0.01	-	-

¹ See Table 2 for information about nutrient rates.

Table 7. Simple correlation coefficients among concentrations of P, K and S in red clover dry matter in June. (Based on 34 observations for S and 35 observations for K and P).

	P	K	S
P	1.00	0.55 (P<0.001)	0.33 (P=0.06)
K		1.00	0.35 (P<0.05)
S			1.00

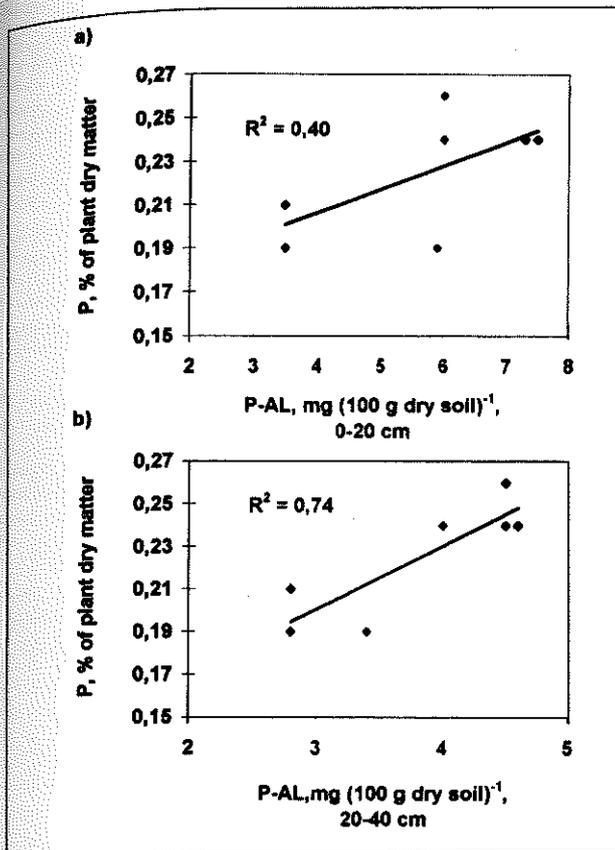


Figure 2. Relationship between herbage P concentration in June (before flowering) and initial soil P-AL values in (a) topsoil and (b) subsoil layers. (Only unfertilized control plots have been included).

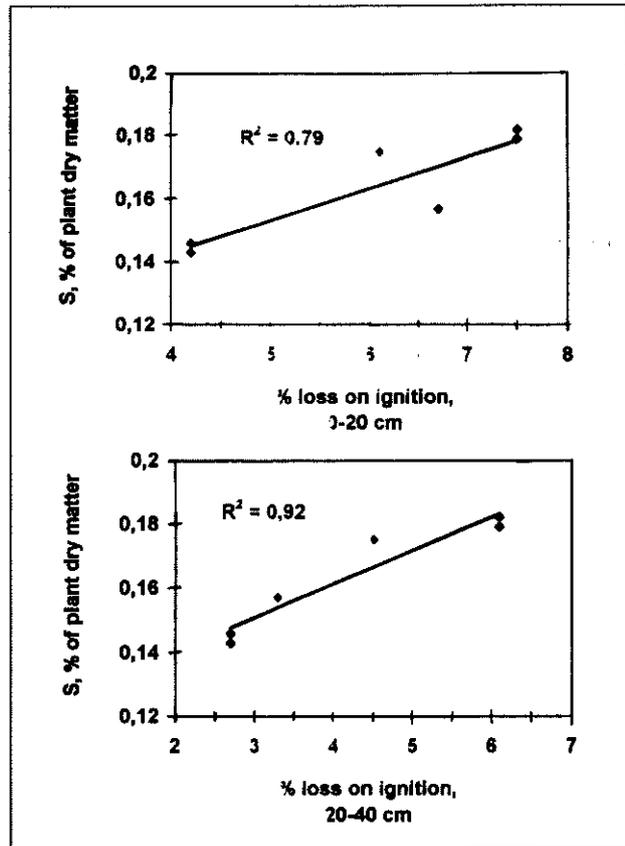


Figure 4. Relationship between herbage S concentration in June (before flowering) and initial ignition losses (not corrected for clay content) in (a) topsoil and (b) subsoil layers. (Only unfertilized control plots have been included).

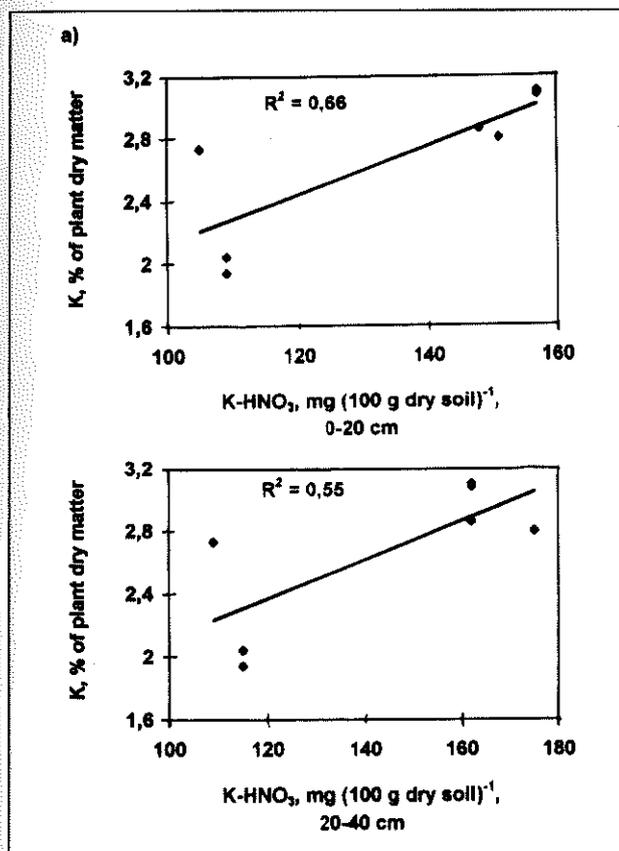


Figure 3. Relationship between herbage K concentration in June (before flowering) and initial soil K-HNO₃ values in (a) topsoil and (b) subsoil layers. (Only unfertilized control plots have been included).

S concentration in plant dry matter, the ratios N/S and S/P are sometimes preferred as indices for plant S status. Unfortunately, the N/S ratio could not be determined for the present material, but S/P ratios of 0.7 – 0.8, as calculated from Table 6, coincide with what Sinclair, Morrison, Smith and Dodds (1996) described as a well-balanced mineral nutrition for white clover.

Organically bound S usually provides the major reservoir of soil S, especially in humid areas (Mengel and Kirkby, 1987). The highly significant correlation between plant S and soil ignition losses (Fig. 4) is therefore not surprising, although it had been expected that the relationship between total soil S and plant S would have been even closer. The inadequacy of the total soil S analysis illustrates, perhaps, why routine analyses for this element have never gained general acceptance, despite the fact that several extraction and analytical procedures have been suggested (Johnson and Fixen, 1990).

According to Bowley, Taylor and Dougherty (1984), tap roots of red clover usually penetrate at least 1 m in well-drained soils. Plants may therefore have a significant uptake of nutrients from lower horizons, and the data presented in Figs. 2-4 clearly indicate that subsoil values should also be taken into consideration when evaluating soil fertility with respect to red clover seed production. Among the experimental sites used in these trials, the soil at Gvarv was clearly the most, and the soil at Våle the least, conducive to red clover seed production.

The reason why potassium sulphate decreased the hard seed

sought in the tenfold difference in seed yield in the first harvest year. It is probable that plants were more exhausted and therefore had a higher mortality after having produced an average of 893 kg seed ha⁻¹ at Gvarv as compared with only 91 kg ha⁻¹ at Våle. A survey among Norwegian seed growers of tetraploid red clover in 1995 showed seed yields to be, on average, 40% lower in second than in first year crops (Aamlid, 1996). From an experimental point of view, second year crops of red clover are often too uneven to produce good experimental data.

In conclusion, these experiments provide no justification for application of P, K or S to red clover seed crops on marine clay soils in SE Norway. Variations in red clover seed yields caused by differences in soil fertility, as identified by ignition losses and test values for P and K throughout the soil profile, seem difficult to alleviate by fertilizer applications.

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