Fertilizer Research **45:** 163–167, 1996.

Selenium concentration in spring wheat as influenced by basal application and top dressing of selenium-enriched fertilizers

S. Tveitnes*, B. R. Singh & L. Ruud
Department of Soil and Water Sciences, Agricultural University of Norway, P.O. Box 5028, N–1432 Ås, Norway
*(*author for correspondence)*

Received 27 July 1995; accepted in revised form 30 April 1996

Key words: Basal dressing, Se-enriched fertilizers, Se-uptake, soil texture, top-dressing, wheat

Abstract

A multisite field experiment was conducted to study the effect of topdressed Se-enriched $Ca(NO_3)_2$ (CN) and basal applied NPK on the selenium (Se) concentration in spring wheat (Triticum aestivum L.). Selenium was applied either through CN (at the rates of 0, 6.45, and 12.91 g Se ha^{-1}) or NPK (5.83 g Se ha^{-1}). Selenium concentration in wheat grains increased consistently with increasing rate of Se-enriched CN or NPK. However, the superiority of Se–enriched CN over NPK in raising the Se concentration in wheat grain depended on location and growth conditions. At the same rate both methods of Se-application were found to be equally effective in raising the Se concentration of wheat grains. The Se concentration of grain was generally higher in the light textured soils than in the medium to heavy textured soils. Without Se application, the Se-concentration in wheat grain was about 16 $\mu g\ kg^{-1}$ which is regarded insufficient to meet the Se requirement for Se in animal and human. Calcium nitrate enriched with 25 mg Se kg^{-1} (6.45 g Se ha^{-1}) increased the Se concentration in wheat grain to a desired level.

Introduction

The Se concentration of plants grown on naturally acidic soils low in Se levels can be increased by adding Se to the soil in the form of selenite or selenate separately or incorporated in NPK fertilizers (Allaway et al., 1967; Yläranta, 1983; Aasen, 1987; Singh, 1991, 1994). Only a small portion of the soil applied Se is utilized by plants. Incorporation of Se-enriched fertilizer in the soil may further reduce the efficiency of Se, because Se is either fixed in the soil (Gissel-Nielsen, 1977) or leached down to the lower layers (Gissel-Nielsen et al., 1984). Therefore, more efficient ways of applying Se to plants, e.g. foliar spray and seed application have been investigated (Cary and Rutzke, 1981; Yläranta, 1985). Top-dressing of Se-enriched fertilizers may be more efficient than basal application (Grant, 1965). This practice has been seldom used in raising the Se concentration of food crops. Although the animal diet in Norway is supplemented with Se through mineral salt of Se added in the animal feed, such supplement in wheat flower used for human consumption is not advocated by the State Health Authorities. It has been practiced to mix Se-rich wheat imported from abroad with Norwegian wheat. In the last decade, the proportion of Norwegian wheat in wheat flour used for bread making is increasing continuously and hence the practice of mixing with imported wheat is not sufficient to meet the dietary requirements of Se. It was therefore considered important to investigate the alternative methods of raising the Se content of wheat in Norway.

Top-dressing of Se-enriched calcium nitrate was found superior to basal Se-application in raising Se-concentration of wheat in a greenhouse experiment (Singh, 1994). It was therefore thought desirable to initiate a multisite field experiment to compare the effect of Se-enriched calcium nitrate topdressed at heading with that of basal dressed NPK-fertilizer on the Se-concentration in spring wheat.

Table 1. Some chemical properties of the soils collected from different sites.

Site	pH (H_2O)	Se mg kg^{-1}	P–AL	K–AL mg 100 g^{-1}	Mg–AL
Ås	5.7	0.29	6.4	7.4	5.2
Apelsvoll	5.8	0.27	6.3	5.7	8.3
Kvithamar	6.2	0.44	21.0	5.4	14.0
Vestfold	6.3	0.13	12.0	12.0	10.0

P–AL = Phosphorus dissolved in a mixture of ammonium lactate (0.1 mol l^{-1}) and acetic acid (0.4 mol l^{-1}), with pH 3.75.

Table 2. Amounts of N, P, K and Se (Na–selenate) applied through NPK or CN fertilizer.

Treatment	Method of Se app.	Basal dose NPK 21–4–10				Top dressed Calcium nitrate	
		N	P	K	Se	N	Se
		Kg ha^{-1}			g ha^{-1}	Kg ha^{-1}	g ha^{-1}
a	–	80	14	37	0	40	0
b	T	80	14	37	0	40	6.45
c	T	80	14	37	0	40	12.91
d	B	80	14	37	5.83	40	0

T = Top dressed.
B = Basal dressing.

Table 3. Grain yield of wheat during the experimental period, mean of treatments.

Experimental sites	Grain yield, kg ha^{-1} 1990	1991	1992	1993	1994
NLH I, Ås	3980	–	700	4050	2520
Apelsvoll, Østre Toten	5020	5210	4920	3570	–
Øsaker, Tune	3000	3350	800	3480	–
Staur, Stange	6270	4320	6510	5890	–
Vestfold	–	4760	4570	5960	–
NLH II, Ås	–	4340	1930	2640	3320
Kvithamar, Stjørdal	–	–	4110	3030	4340
Stjørdal Res. Group	–	–	1600	4010	3220

Materials and Methods

Field experiments were conducted at 8 different field sites with varying soil properties in the cereal growing areas of Norway: The sites were at Ås (Agricultural University of Norway) and Stjørdal (Kvithamar Research Centre and Stjørdal Research Group) and one in each of the communities Vestfold, Tune (Øsaker), Stange (Stange Research Station), Østre Toten (Apelsvoll Research Centre). A composite soil sample on replicate basis, was collected prior to sowing from each of the sites. The soils from Ås and Øsaker were similar in the physio-chemical properties and the same was the case with those from Apelsvoll and Staur. Therefore, the soil chemical properties presented in Table 1 are only from distinctly different soils. Easily soluble P, K and Mg were determined according to Egnér (1960). Se was determined by the hydride generation atomic absorption spectrophotometry method using dry ashing procedure (Øien et al., 1988).

A basal dose of NPK (21–4–10) at the rate of 80 kg N ha^{-1} was applied to all the treatments. Calcium nitrate was applied at the rate of 40 kg N ha^{-1}. The amounts of N, P, K and Se applied through these fertilizers are shown in Table 2.

The treatments were laid out in a randomized block design with 4 replicates. The plot size was 24 m^2(3 × 8) with a harvested area of 12 m^2.

Selenium (Na selenate) either in the NPK or in the CN fertilizers was incorporated during the manufacture process. Selenium-enriched NPK fertilizer was applied prior to sowing in spring. The Se-enriched CN was top-dressed at the initiation of heading as per the practice followed by the farmers for top-dressing of N-fertilizers. Since farmers use top-dressing of CN for increasing the protein content of their produce, the CN enriched with Se could also raise the Se concentration of wheat grain without any additional cost of application.

Different varieties of spring wheat were used. At Stjørdal and Østre Toten wheat varieties Runar and Bastian, respectively were grown, while at the other sites the variety Tjalve was used. No varietal differences in the Se content of wheat grains are apparent in this study.

The crop was harvested at maturity, threshed to separate grain and straw but only the grain samples were analyzed for Se. The Se concentration in the plant sample was determined by atomic absorption spectrophotometry using the method developed by Øien et al. (1988).

Analysis of variance of grain yield was carried out by the General Linear Models (GLM) procedure of SAS. (SAS Institute, 1985).

Table 4. Se concentration ($\mu g\ kg^{-1}$) in wheat grain at various sites, mean values of the whole experimental period.

	No of years	Se rates (g ha^{-1})							
		0		6.45		12.91		5.83	
		–		T		T		B	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
NLH I, Ås	3	11	2	162	147	370	309	339	140
NLH II, Ås	2	27	17	126	23	234	116	177	243
Apelsvoll	3	24	29	156	213	409	431	213	182
Staur	4	7	3	162	49	487	216	153	66
Øsaker	4	94	31	192	101	449	380	148	122
Kvithamar	3	20	17	291	145	645	320	174	13
Vestfold	1	5	–	65	–	319	84	151	61
Stjørdal	2	17	1	167	106	408	269	373	105

T = Top dressed.
B = Basal dressing.

Table 5. Se uptake, $\mu g\ ha^{-1}$, in wheat grain at various sites, mean values of the whole experimental period.

	No of years	Se rates (g ha^{-1})							
		0		6.45		12.91		5.83	
		–		T		T		B	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
NLH I, Ås	3	2.7	1.8	44.3	38.8	112.7	95.1	76.6	47.9
NLH II, Ås	2	10.1	8.4	39.6	5.9	70.9	15.5	70.9	15.5
Apelsvoll	3	11.7	15.1	106.0	88.7	237.7	207.6	65.4	36.3
Staur	4	6.8	4.4	97.3	30.6	296.6	137.2	93.0	42.5
Øsaker	4	25.4	16.4	54.1	44.6	130.3	148.8	37.5	44.1
Kvithamar	3	8.0	7.9	114.2	66.4	255.9	164.2	66.7	12.6
Vestfold	1	3.2	–	37.9	–	166.6	72.0	77.7	15.1
Stjørdal	2	3.9	1.4	50.1	50.8	115.6	115.5	81.6	13.0

T = Top dressed.
B= Basal dressing.

Results and Discussion

Grain yields

The grain and straw yields did not differ significantly among treatments and they were also not affected by the time of application of the Se-enriched fertilizers (Table 3) in any of the years under investigation. Hence, only the mean yields are presented in Table 3. Yield levels in 1992 were very low at Ås and Øsaker due to a dry spell in late spring and early summer.

Se concentration

With no application of Se, the Se-concentration in wheat grains was about 16 $\mu g\ kg^{-1}$ when the Øsaker site was not included. At this site the Se concentration was considerably higher (Table 4). The concentration of Se below 20 $\mu g\ kg^{-1}$ is regarded insufficient to satisfy the dietary requirements in animals and humans.

The concentration of Se in wheat grain increased with increasing rate of Se applied in all years (Table 4). Since the trend in Se-concentration was similar from year to year, only mean values for all the years under investigation are presented in Table 4.

When growth was poor, e.g. due to dry spells during the growth period, basal dressing of Se fertilizer was

Table 6. Concentration and uptake of Se in grains as influenced by crop yield level and Se-application in 1992.

Site	Mean grain yield kg ha^{-1}	Se-concentration ng kg^{-1}				Se-uptake mg ha^{-1}			
		Se-rates g ha^{-1}							
		0 –	6.45 T	12.90 T	5.82 B	0 –	6.45 T	12.90 T	5.82 B
Crop yield <2000 kg ha^{-1}									
NLH II, Ås	1930	10	62	185	370	20	130	330	730
Øsaker	800	94	106	274	205	70	130	270	140
NLH I, Ås	700	10	25	52	327	10	20	30	26
Stjørdal	1600	18	92	217	447	30	140	340	720
Crop yield >2500 kg ha^{-1}									
Apelsvoll	4920	7	200	420	200	30	980	212	99
Staur	6510	11	192	491	235	70	1150	2960	1500
Vestfold	4570	56	161	259	194	250	760	1160	880
Kvithamar	4110	8	226	497	183	30	960	1970	770

T= Top dressed.
B = Basal dressing.

superior to topdressing in increasing Se-concentration and Se-uptake in wheat grains.

There were large variation in Se-concentration of wheat grains among sites. This may be due to differences in texture and chemical soil factors. Selenium is strongly adsorbed by clays. The sites at Ås, Stjørdal, Apelsvoll and Vestfold showed a higher availability of Se in basal dressed Se-enriched NPK (B) than in top dressed CN (T) applied at a similar rate (Table 4). At Kvithamar the opposite was the case, while the remaining sites showed only minor differences between the treatments. Application of 12.9 g ha^{-1} Se more than doubled the concentration of Se in the grains as compared to 6.45 g ha^{-1}.

The Se-enriched NPK applied as a basal dose (treatment B) was generally found to be as effective as the top-dressed Se-enriched CN (treatment T) in raising the Se concentration. The Se levels in the applied fertilizer in these treatments were generally equal, 6.45 g ha^{-1} (T) and 5.83 g ha^{-1} (B). It has been reported that soil application of Se is a less efficient means to increase the Se concentration in plants than foliar or seed applications (Sima & Gissel-Nielsen, 1985; Yläranta, 1984). The results of the present study suggest that top-dressing of Se-enriched calcium nitrate and basal dressing with Se-enriched NPK-fertilizer are effective methods for raising the Se concentration in wheat grain under normal growth conditions. However, the superiority of one method over the other is probably dependent on soil textures and rainfall distribution during the growing season.

At all the sites, the concentration and uptake of Se increased progressively with increased rates of the Se-enriched CN application. Se concentration was generally higher in the wheat grain from Apelsvoll and Staur sites than in that from Ås or Øsaker sites, with minor exceptions. Similarly, the total uptake of Se was 2 to 3 times higher at the former sites as compared to the latter (Table 5). The difference in the total uptake of Se among sites were larger with topdressed CN than with basal dressing of NPK (Table 5). The differences in the concentration of Se among soils can be related to the soil properties and especially the soil texture. The soils from Apelsvoll and Staur sites were of morainic nature with a sandy loam texture whereas those from Ås and Øsaker were of loam to silty clay in texture. Thus the textural variations among soils seem responsible for the differences in the Se uptake at different sites in this study. Cary et al. (1967) found that soil texture had a large influence in determining the initial rate of Se uptake by alfalfa. The negative correlation between clay content of the soil and the Se content of the plant has been reported (Bisbjerg & Gissel-Nielsen, 1969; Gissel-Nielsen, 1971).

The first rate of Se application (25 mg Se kg^{-1} fertilizer or 6.45 g ha$^{-1)}$ seems optimum at all the sites to increase the Se concentration in wheat grain to a desired level (0.1 to 0.2 mg kg^{-1}). The basal application of the Se enriched NPK was generally equally effective as that of the Se-enriched CN top-dressed at heading. This differs from the results obtained in the greenhouse experiments (Singh 1991, 1994), where basal application of Se enriched NPK was found to be inferior to the application of the Se enriched CN, topdressed at heading. It is known that in pot experiments roots are confined in limited soil volume as compared to field conditions and hence often such variations among greenhouse and field experiments are observed.

It is reported that the uptake of Se by plants is governed by many soil and plant factors and a slight change in any of these factors may shift the uptake pattern (Aasen, 1987; Gissel-Nielsen, 1984, Gupta & Winter, 1981; Yläranta, 1983, Mikkelsen et al., 1989; Singh, 1994).

Effect of yield level on Se-concentration and uptake

Dry spells in May and June of 1992 caused reduced nutrient uptake, poor growth and low yields at some of the sites (Table 3). When the sites were grouped according to grain yield levels, i.e. <2000 kg ha^{-1} and >2500 kg ha^{-1}, a distinct pattern of Se concentration and uptake was visible (Table 6). Table 6 shows that mostly the Se concentration in grains was higher with normal yields as compared to poor yield levels. The data in Table 6 also show that on the sites with poor growth, basal application of Se-enriched NPK increased the Se-concentration in wheat to a higher level than that achieved by the topdressed CN. This may be attributed to lower root activity to take up surface applied Se when the total plant growth was poor.

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