Potassium Inputs to Grass Seed Crops

Trygve Sveen Aamlid[1]

ABSTRACT

The application of increasing rates of potassium (40, 80 or 120 kg K ha^{-1} as KCl), in most cases either in autumn or in spring, was compared with no application in 13 field experiments comprising 24 seed harvests on various soils in SE Norway from 1989 to 1995. There were nine experiments with *Festuca pratensis* Hud., two with *Phleum pratense* L. and one for each of the species *Festuca rubra* L., *Bromus inermis* Leyss and *Poa pratensis* L. On soils with low K reserves, K applications, notably in spring, increased straw dry matter yield and straw K concentration but had no effect on seed yield. Seed yields on soils with greater K reserves were higher following autumn than with spring application, but the optimal rate of K was not higher than 40 kg ha^{-1}. Treatments had no effect on seed K concentration or the removal of K in seed, which accounted for only 3-6% of the total removal of K in straw and seed. On average for all experiments, lodging, thousand seed weight or germination were not influenced by K. Even though soil K levels will be somewhat reduced during the seed production years, is concluded that grass seed crops should not receive more than 40 kg K ha^{-1}, and that this should be applied either in autumn or split between autumn and spring.

Additional index words: Bromus inermis, Festuca pratensis, Festuca rubra, Phleum pratense, Poa pratensis, potassium, seed production, straw yield.

INTRODUCTION

Besides nitrogen (N), potassium (K) is the mineral element taken up in greatest quantities by grass seed crops. Operating as a free cation (K^+), potassium plays an important role in phloem transport, cell turgor regulation and enzyme activation, but it can also accumulate to concentrations which are antagonistic to the uptake and translocation of other elements. This is especially the case in grasses, which have an efficient root system capable of depleting soils for exchangeable K, and which have a tendency to absorb monovalent cations at the expense of divalent ones (Mengel and Kirby, 1987).

Potassium in the soil is generally associated with clay minerals. In Norway, two standard procedures are used for the determination of soil K: (1) Extraction with a solution of 1 M nitric acid (K-KNO_3; Reitemeier, 1951); and (2) extraction with a so-called 'AL-solution' consisting of 0.1 M ammonium-lactate and 0.4 M acidic acid (pH 3.75); the latter extract is commonly used also for the determination of plant-available phosphorus (P-AL), magnesium (Mg-AL) and calcium (Ca-AL) (Egner, Riehm and Domingo, 1960). While K-AL reflects cultivation practices that affect grass dry matter yields primarily in the first ley year, K-HNO_3 is the preferred indicator for soil K reserves that influence yields throughout the ley period (Semb and Øien, 1961; Lunnan, 1993).

While there are many reports on the effects of K on forage yield and quality, comparatively few have been published on the K requirement in grass seed production. Fulkerson, Weir and McRostie (1951) indicated that in Ontario, Canada, the application of 40 kg K ha^{-1} as KCl to seed crops receiving no other fertilizer increased panicle number and seed yield of cocksfoot (*Dactylis glomerata* L.), but had no effect on seed yields of meadow fescue (*Festuca pratensis* Huds.), red fescue (*Festuca rubra* L.), smooth meadowgrass (*Poa pratensis* L.) or timothy (*Phleum pratense* L.). Seed crops of perennial ryegrass (*Lolium perenne* L.) showed no response to K fertilizers in British (Chumbley and Jones, 1973) and New Zealand (Brown, 1980) trials; this was also confirmed in a recent survey of 80 New Zealand seed crops (Rolston, Rowarth, Young and Mueller-Warrant, 1997). Even on light soils, seed yields and panicle numbers of German seed crops of cocksfoot, meadow fescue, timothy and perennial ryegrass were unchanged if a total input of 400 kg ha^{-1} was incorporated into the soil before sowing or split into applications every autumn during a two or three year ley period; these experiments included no control treatment without K (Lampeter and Schoberlein, 1969). From Hungary Janovszky (1983) reported that elimination of K inputs had very little effect on seed yields of smooth bromegrass (*Bromus inermis* Leyss.) or meadow fescue. In a Danish investigation, application of 100 kg K ha^{-1} in addition to adequate amounts of N and P had little or no effect on seed yields of meadow fescue or perennial ryegrass, despite the fact that these crops were grown in a long-term trial where the soil had been depleted for K for 17 years (Nordestgaard, 1990). In a pot experiment with soil taken from the same long-term trial, Nordestgaard (1990) found that an input corresponding to 200 kg K ha^{-1} significantly decreased seed yields of smooth meadowgrass compared to inputs of 0 or 100 kg K ha^{-1}. Dissemination of these results among Danish seed growers led to a dramatic reduction in the use of K in grass seed crops in that country (Nordestgaard, 1990; Svensson, 1994).

Research in Oregon, USA, has focused on the impact of straw and residue management on the K balance of grass seed crops. Compared to open field burning, straw removal led to lower soil test levels and lower concentrations of K in the straw of tall fescue (*Festuca arundinacea* Schreb.) and perennial ryegrass, but even with straw removal, seed yields were rarely increased, and the seed K concentration did not change following K application (Hart, Horneck, Young and Silberstein, 1991; Horneck, Hart, Young and Silberstein, 1992; Horneck, Hart and Young, 1994). Horneck *et al.* (1994) recommended that seed crops of tall fescue and perennial ryegrass be fertilized with K only if

[1] *The Norwegian Crop Research Institute, Division Landvik, N-4890 Grimstad, Norway.* *Accepted for publication 9 October 1998.*

ammoniumacetate-extractable soil K was lower than 150 and 100 ppm, respectively.

On average for three levels of N and three levels of P given to 25 timothy crops in Norway from 1959 through to 1967, seed yields were 353,384 and 366 kg ha^{-1} after application of 0,82 and 163 kg K ha^{-1}, respectively (Wølner, 1971). These trials were mainly conducted on moraine soils with intermediate to high levels of K-AL. In the same trials, percent lodging averaged 39, 32 and 31%, respectively, and the straw yields were, in turn, 7960, 8480 and 8420 kg ha^{-1} (Wølner, 1971). A later series comprising 13 experiments mainly on marine silt loams from 1972 to 1977 showed no difference in seed yield whether the same amount of nitrogen was given in compound fertilizers Fullgjødsel® (NPK 16-7-12) or Fullgjødsel® (NPK 20-5-9) (Torskœs, unpublished data).

Except for timothy, Norwegian seed crops commonly receive N both in autumn and in spring. Up to now, recommended practice has been to apply pure N as Kalksalpeter ™ (calcium-nitrate, 15.5% N) in autumn and a compound fertilizer rich in P and K (commonly Fullgjødsel® or Fullgjødsel® NPK 17-5-13) in spring. There are, however, indications that K inputs in spring may reduce dry matter yield in the first ley year on soils with high K reserves (Lunnan, 1993), and Petersen (1981) reported that a balanced input of N, P and K rather than of pure N in autumn improves winter hardiness and thus spring growth of many grasses. The objectives of the present research were to determine both the optimal K rate, and the optimal time of K application, to grass seed crops.

MATERIALS AND METHODS

From 1989 through to 1993 a total of 12 experimental fields were laid out at The Norwegian Crops Research Institute, division Landvik, and on farms throughout the seed production area of SE Norway (Fig.1). Information about grass species, soil types, initial soil tests values (0-20 cm soil layer) and the number of seed harvests in each trial is indicated in Table 1. With exceptions as indicated by footnotes in the table, all fields were laid out in the autumn of the sowing year, usually after harvest of a spring barley or spring wheat cover crop. Plot size was 8 x 2 m, of which 6.5 m x 1.5 m was harvested for seed.

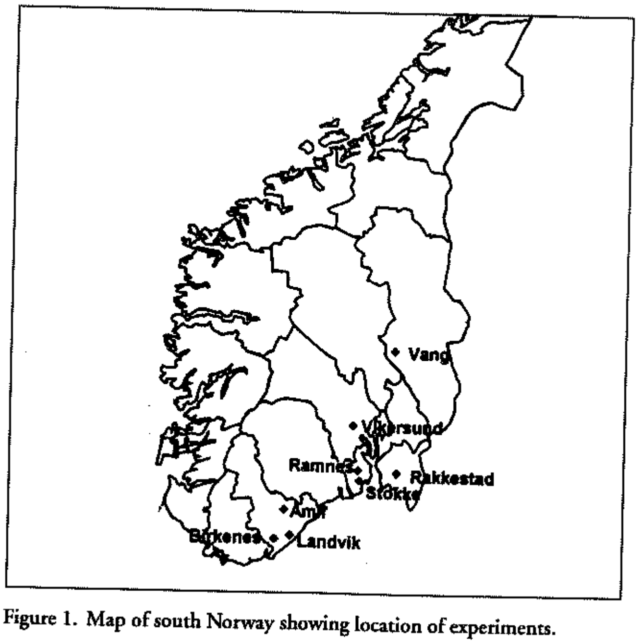

Figure 1. Map of south Norway showing location of experiments.

Except for experiments which received K in spring only, the experimental plan comprised seven treatments which were completely randomized into each of three replicates (ie. nil K, 40 or 80 or 120 kg K ha^{-1} in autumn, 40 or 80 or 120 kg K ha^{-1} in spring). K was supplied as KCl (49%K). Autumn application was in late August or September and spring application at the start of growth in April or early May. On the same dates nitrogen was applied, either as HYDRO-KAS ™ (calcium-ammonium-nitrate, 28% N; trials in Ramnes only) or as Kalksalpetr ™ (calciumnitrate, 15.5% N; all other trials) and at rates depending on species (Table 2). For most experiments P was applied at rates up to 40 kg ha^{-1} as superphosphate (9% P) in the spring of the first seed harvest year, but not later in the experimental period. This practice ensured fairly stable P-AL-levels in trials that were harvested only in one or two years but in the trials which were harvested in three consecutive years at Landvik, P-AL values dropped 29-36% during the experimental period. Many of the trials were irrigated, especially those on light soils.

Per cent lodging was determined before seed harvest in most experiments. At Landvik and in some of the on-farm trials, panicle number was counted within a 0.25 m^2 or 0.36 m^2 subplot in each plot.

The experiments were combined directly with field plot combines at 25-35% seed moisture content. The dry matter yield of straw was determined at Landvik and in one of the on-farm trials (Amli). Straw was always baled off the experiments, and in meadow fescue, red fescue and smooth bromegrass, stubble and regrowth was usually cut and removed before autumn application of N and K.

Seed harvested from the on-farm trails was dried locally before transport to Landvik for seed cleaning. After cleaning, one sample per plot or, in a few cases, one common sample per treatment, was analyzed for purity and thousand seed weight in the seed laboratory. Samples from each plot in a total of seven crops were germinated in accordance with internationally agreed methodology (ISTA, 1996).

In most trials, one soil sample for pH, P-AL, K-AL and K-HNO_3 analyses was taken from each treatment (common for the three replicates) every year after seed harvest. In the trials with meadow fescue, red fescue and smooth bromegrass at Landvik, yearly samples of seed and straw (one per treatment) were also analysed for K. In the last harvest year, analyses for magnesium (Mg) in seed and straw were also included.

Experimental data were analysed statistically by the SAS procedures PROC ANOVA and PROC GLM (SAS, 1990). Each crop was considered as one replicate in the common analyses. For experiments involving different rates of K both in autumn and spring, analyses were performed across species and separately for light (initial K-HNO_3 < 40 mg K (100 g dry soil)$^{-1}$) and heavy (initial K-HNO_3 > 80 mg K (100 g dry soil)$^{-1}$) soils. Effects of K treatments were split into the contrasts 'No K vs. K' (1 degree of freedom (DF), 'Application time' (1DF), 'K-rate' (2DF) and the interaction 'Application time x K rate' (2 DF). The latter two contrasts comprised both linear and quadratic effects of K rates. P-values for significant effects ($P<0.05$) and tendencies ($P<0.2$) are given in the tables. Mean data for each species are presented in Table 3 but will usually not be discussed as they are confounded with various soil types.

Table 1. Sowing years, locations, grass species, soil types, initial soil test values and number of seed harvest years in experiments with K application to grass seed crops.

Sowing Year	Location	Species	Soil type	pH (H_2O)	Initial soil test values P-AL mg	K-AL (100 g dry soil)$^{-1}$	$K-HNO_3$	Seed harvest years
1989	Stokke	*Festuca pratensis*	Silt loam	6.8	7.9	10.6	117	2[1]
1990	Birkenes	*Festuca pratensis*	Sandy loam	6.4	21.4	16.2	159	2
1990	Landvik	*Poa pratensis*	Sand	6.0	41.0	8.6	34	2
1991	Landvik	*Festuca pratensis*	Sand	6.1	38.7	8.0	17	3[2]
1991	Landvik	*Bromus inermis*	Loam	5.8	17.2	14.2	87	3[2]
1991	Landvik	*Festuca rubra*	Silt loam	5.7	10.0	12.8	148	3
1992	Rakkestad	*Phleum pratense*	Silty clay loam	6.1	8.7	22.1	104	1
1992	Amli	*Festuca pratensis*	Sand	61	3.2	6.2	10	1
1992	Ramnes	*Festuca pratensis*	Silty clay loam	6.0	9.6	15.5	134	1
1993	Vikersund	*Festuca pratensis*	Silt loam	6.2	8.4	10.9	132	2
1993	Vang	*Phleum pratense*	Moraine	6.5	4.9	5.2	30	2
1993	Ramnes	*Festuca pratensis*	Silty clay loam	6.6	9.8	26.5	143	2

[1] *In both seed harvest years, this experiment comprised different levels of K in spring only*
[2] *In the first seed harvest year, these experiments comprised different levels of K in spring only*

Table 2. Nitrogen inputs (kg N ha^{-1}) in autumn and spring to different grass species in experiments with K application to grass seed crops.

	Festuca pratensis	*Festuca rubra*	*Bromus inermis*	*Phleum pratense*	*Poa pratensis*
Autumn	30	50	50	0	50
Spring	80	50	80	80	50

RESULTS

Seed yields

Although the first year's seed yield of meadow fescue on a sandy soil at Landvik tended to decrease with increasing rates of K, no significant effect of K treatment could be detected in trials when K was applied in spring only (Table 4).

Seed yields on light soils were not significantly affected by K treatments in any of the experiments, including application in autumn and spring (Table 5). On heavy soils, application in autumn produced higher seed yields than application in spring, and 40 kg K ha^{-1} was superior to higher rates of K. Since these effects were roughly the same in all seed harvest years, only mean data are presented in Table 5. The interaction application time x K rate was not significant on either light or heavy soils.

Panicle numbers

No effect of K on panicle numbers could be observed in the two crops at Landvik which received K in spring only. In the complete experiments, panicle number was not affected by K treatments on light soils but increased with K application on heavy soils (Table 5). In the latter case the optimal rate of K for panicle production tended (P=0.16) to be higher with autumn than with spring application (Fig. 2).

Straw yields

No effect of K on straw yields could be observed in the two crops at Landvik which received K only in spring. Straw yields tended to be stimulated by K in complete experiments on light soils; in this case spring inputs seemed to have a greater effect than application in autumn (Table 5). In contrast, there was a tendency for high spring applications to decrease straw yield on heavy soils.

K concentration and removal in seed and straw dry matter

No effect of K treatments on the concentration or removal of K in seed or straw could be detected in any of the

Table 3 Seed yields, per cent K and Mg in seed dry matter, K and Mg removed with seed, straw yields, per cent K and Mg removed with straw, per cent lodging, panicle numbers, thousand seed weights, interim germination and germination on average, for species in experiments with K application to grass seed crops in autumn and spring.

	Festuca pratensis	*Festuca Rubra*	*Bromus inermis*	*Phleum pratense*	*Poa pratensis*
Seed yield (kg ha^{-1})[2]	533 (10)[5]	656 (3)	592 (2)	629 (3)	183 (2)
Per cent K in seed dry matter	0.58 (2)	0.59(3)	0.44(2)	-[6]	-
K removed with seed (kg ha^{-1})	4.2 (2)	3.4(3)	2.3(2)	-	-
Per cent Mg in seed dry matter	0.14 (1)	0.10(1)	0.11(1)	-	-
Mg removed with seed (kg ha^{-1})	0.73 (1)	0.54(1)	0.49(1)	-	-
Straw yield (kg ha^{-1})[3]	9150 (3)	3530 (3)	8340 (2)	-	-
Per cent K in straw dry matter	1.45(2)	1.39(3)	0.87(2)	-	-
K removed with straw (kg ha^{-1})	94.9(2)	49.5(3)	70.3(2)	-	-
Per cent Mg in straw dry matter	0.18(1)	0.08(1)	0.08(1)	-	-
Mg removed with straw (kg ha^{-1})	10.5(1)	3.0(1)	5.9(1)	-	-
Lodging,(%)	43 (8)	0 (2)	12 (2)	11 (3)	0 (2)
Panicle number	860 (6)	1477 (3)	362 (2)	-	439 (2)
Thousand seed weight (mg)[4]	2302 (10)	1061 (3)	3563 (2)	637 (3)	264 (2)
Interim germination (%)	90 (2)	-	68 (2)	92 (1)	78 (2)
Germination (%)	92 (2)	-	78 (2)	95 (1)	84 (2)

[1] *All data are means of K treatments*
[2] *100% purity, 14% moisture content*
[3] *100% dry matter*
[4] *14% moisture content*
[5] *number of crops in which data were collected*
[6] *no data collected*

experiments, including K in spring only. In the first year crop of meadow fescue at Landvik, the average concentrations of K were 0.59 and 1.00% in seed and straw dry matter, respectively. For smooth bromegrass, the corresponding figures were 0.45 and 0.71%.

In the experiments including both autumn and spring application the concentration and removal of K in straw dry matter was mostly affected on light soils (Table 5). For these crops, both meadow fescue, the contrasts 'No K vs. K' 'Application time' and 'K rate' were all significant. For K removal in straw there tended (P=0.07) to be an interaction in that increasing rates of K had a greater impact when applied in spring than in autumn (Fig. 3).

Although values tended to be lower on unfertilized control plots, the effects of treatments on straw K concentration and removal were small and insignificant on heavy soils (Table 5).

Seed K concentration or removal was not affected by K treatments on either light or heavy soils.

Mg concentration and removal in seed and straw dry matter

In the third year crop of meadow fescue at Landvik, the concentration of Mg in straw dry matter was 0.21% on unfertilized control plots as compared with, on average for K rates, 0.19 and 0.16% on plots receiving K in autumn and spring, respectively. The averages for K rates were, in turn, 0.19, 0.18 and 0.16 after inputs of 40, 80, and 120kg K ha^{-1}. The lowest and highest removal of Mg in straw, 8.7 and 12.8 kg ha^{-1}, occurred on plots which had received 120 kg K ha^{-1} in spring and 40 kg K ha^{-1} in autumn, respectively.

K treatments exerted little influence on Mg concentration and removal in straw dry matter on heavy soils, and this was also the case for Mg in seed on both soil types.

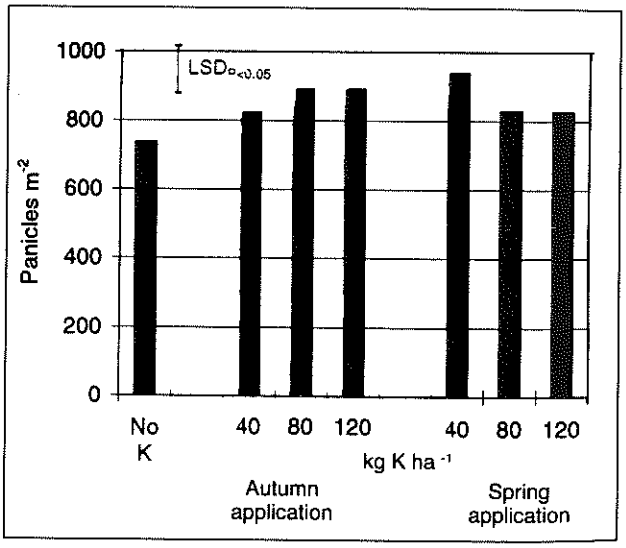

Figure 2. Panicle density after application of increasing rates of K in autumn and in spring. Means of 8 harvests on heavy soils.

Lodging

In the first year crop of meadow fescue at Landvik, lodging decreased from 47% on unfertilized control plots to 43, 33 and 28% on plots which had received 40, 80 and 120 kg K ha^{-1} in spring, respectively. No other effect on lodging could be detected in experiments receiving K in spring only.

In the complete experiments, a significant effect of K on lodging was recorded only in a second year crop of meadow fescue, in which lodging averaged 77% on unfertilized plots as compared to 60% for plots that had received K. Similar tendencies were recorded in some other crops, but as an overall average, the effect of K on lodging was not significant.

Table 4 Seed yield (kg ha^{-1}) in experiments with K application in spring only.[1]

Location	Stokke		Landvik		Mean
Species	*Festuca pratensis*	*Festuca patensis*	*Festuca pratensis*	*Bromus inermis*	
	1[2]	2[2]	1[2]	1[2]	
0 kg K ha^{-1}	505	806	909	874	774
40 kg K ha^{-1}	507	867	859	863	774
80 kg K ha^{-1}	588	811	846	869	779
120 kg K ha^{-1}	540	878	758	894	768
P-value	>0.2	>0.2	0.15	>0.2	>0.2

[1] *100% purity, 14% moisture content* [2] *seed harvest year*

Table 5. Seed yield, panicle number, straw yield, K in straw dry matter and K removal in straw on light and heavy soils as affected by various contrasts of K treatments.

Light soils (initial K-HNO_3 < 40 mg 100 g dry soil $^{-1}$)	Seed yield (kg ha^{-1})	Panicle Number	Straw Yield (kg ha^{-1})	K in straw Dry matter (%)	K Removal In straw (kg ha^{-1})
Number of seed crops	7	5	3	2	2
No K vs. K					
No K	621	842	8580	1.13	71
K	616	869	9250	1.50	99
P-value	>0.2	>0.2	0.09	<0.001	<0.001
Time of K application					
Autumn	618	883	8970	1.40	91
Spring	615	855	9520	1.60	107
P-value	>0.2	>0.2	0.07	<0.01	<0.001
K rate					
40	615	880	9340	1.38	91
80	610	829	8990	1.47	97
120	624	898	9420	1.65	109
P-value	>0.2	0.14	>0.2	<0.01	<0.01

Heavy soils (initial K-HNO_3 > 80 mg 100 g dry soil $^{-1}$)	Seed yield (kg ha^{-1})	Panicle Number	Straw Yield (kg ha^{-1})	K in straw Dry matter (%)	K Removal In straw (kg ha^{-1})
Number of seed crops	13	8	5	5	5
No K vs. K					
No K	491	737	5410	1.10	54
K	494	866	5360	1.19	58
P-value	>0.2	<0.05	>0.2	0.07	0.18
Time of K application					
Autumn	506	868	5500	1.18	58
Spring	482	864	5230	1.21	59
P-value	<0.01	>0.2	0.09	>0.2	>0.2
K rate					
40	510	881	5490	1.17	60
80	482	860	5190	1.21	57
120	491	859	5410	1.20	58
P-value	<0.05	>0.2	>0.2	>0.2	>0.2

[1] *100% purity, 14% moisture content* [2] *100% dry matter*

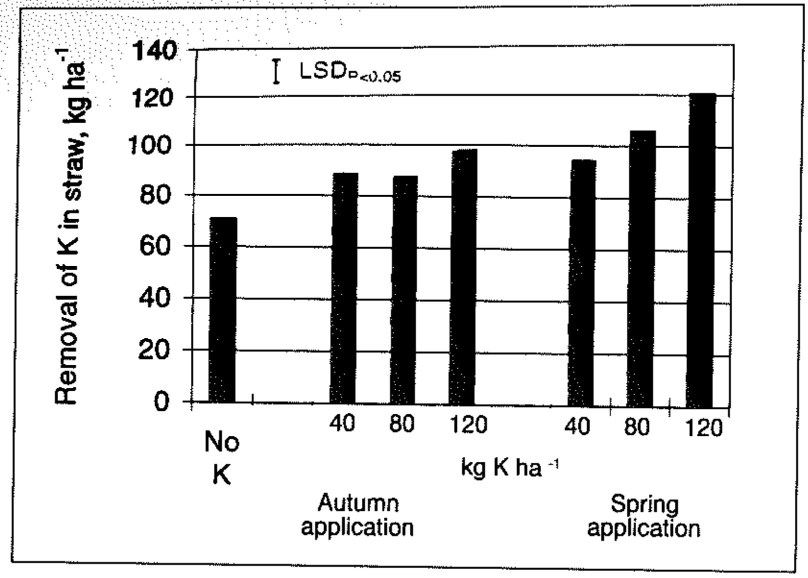

Figure 3. Removal of K in straw dry matter after application of increasing rates of K in autumn and in spring. Means of 2 harvests in meadow fescue on a light soil.

Thousand seed weight

Thousand seed weight was not affected by treatments in any of the crops which received K in spring only. This was also the case in the overall analyses for complete experiments on both light and heavy soils, although there were two experiments on heavy soils in which seeds were significantly heavier after autumn application than after no application in spring.

Germination

Autumn application of K tended ($P=0.10$) to give a higher interim germination in one out of seven experiments for which germination analysis was accomplished. In this crop, which also had a higher thousand seed weight after autumn application, the interim germination was 86, 90 and 87% with no K and K in autumn and spring, respectively. The corresponding final germination counts were 89, 92 and 91%. On average for the seven experiments germination was not significantly affected by K inputs.

Soil tests

K-AL values were not affected by the time of K application, but increasingly affected by K rates during the experimental period (Table 6). While an annual input of 40-80 kg K ha was sufficient to maintain K-AL at initial values on heavy soils, even the highest rate could not prevent a drop on light soils. K-HNO_3 values were generally not affected by K treatments on heavy soils, but on the light soils, the contrasts 'No K vs. K' and 'K rate' were both significant ($P<0.01$ and $P<0.05$, respectively) in the autumn of the second harvest year. Average values after application of 0, 40, 80 and 120 kg K ha^{-1} were 17, 20, 21 and 22 mg (100 g dry soil^{-1}), respectively; similar tendencies were recorded also in the first and third year.

Soil pH or P-AL were not affected by K treatments.

DISCUSSION

Along with most of the literature cited in the introduction of this paper, the results indicate that K inputs are of minor importance in grass seed production. The only significant effects of K on seed yield were detected on soils with large K reserves, on which the optimal rate was 40 kg K ha $^{-1}$ and autumn was the optimal time for application (Table 5). Panicle numbers also increased with K on such soils, but the relatively large difference compared to unfertilized control

Table 6 K-AL (mg (100 g dry soil) $^{-1}$) on light and heavy soils in the autumn of the first, second and third seed harvest year as affected by various contrasts of K treatments. Initial values at the start of experimentation have been indicated.

	Light soils (intial K-NHO$_3$ < 40 mg 100 g dry soil $^{-1}$)			Heavy soils (intial K-HNO$_3$> 80 mg 100g dry soil $^{-1}$)		
Seed harvest year	1	2	3	1	2	3
Number of seed crops	1	3	1	1	5	2
Intial K-AL (mean)	5.2	7.3	8.0	19.2	16.1	13.5
No K vs. K						
No K	3.9	3.5	2.7	17.9	12.7	10.8
K	4.7	5.8	5.8	20.6	16.1	15.2
P-value	-	<0.01	-	<0.05	<0.05	<0.05
Application time						
Autumn	4.7	5.5	4.8	21.2	16.1	14.5
Spring	4.6	6.0	4.7	20.0	16.0	15.8
P-value	-	>0.2	-	0.19	>0.2	>0.2
K-rate, kg ha^{-1}						
40	4.4	4.8	3.3	19.8	14.5	13.4
80	4.7	5.6	4.2	21.4	15.5	14.8
120	4.9	6.9	6.8	20.0	18.2	17.3
P-value	-	<0.05	-	>0.2	<0.05	0.12

[1] *100% purity, 14% moisture content*
[2] *seed harvest year*

plots was not reflected in seed yield, indicating compensation from other yield components.

Most surprisingly, K inputs did not enhance seed production on light soils with low K reserves (Table 5). In the first year crop of meadow fescue on a sandy soil at Landvik, seed yield actually tended to decline with increasing rate of K in spring (Table 4). At the same time, K stimulated straw production on light soils (Table 5); this confirms the general opinion that K is of greater importance and more related to soil test values in forage than in seed production (Rolston *et al.*, 1997). As many forage trials (e.g. Lunnan, 1993) have shown increasing responses to K with increasing age of stand, one reason for the low requirement for K in grass seed production may be that seed crops are seldom maintained for more than two or three harvest years.

In spite of the fact that straw yields of perennial ryegrass and tall fescue removed up to 100 and 300 kg K ha^{-1}, respectively, Horneck *et al.* (1994) argued for 50 and 100 kg^{-1} ha as economical inputs to non-burned seed crops of the two species. The authors did not advocate a practice where the total K-removal is replaced in the seed harvest years. The present findings substantiate these recommendations and suggest that a certain drop in soil K-AL values has to be accepted during the seed production period. It is a general experience that grasses respond less favourably to K application that dicotyledonous plants (Mengel and Kirkby, 1987), and the most economical solution will therefore be to fertilize other crops in the rotation such as to compensate for a least some of the K deficit during the seed production years.

Potassium uptake by grasses is always most intense in the vegetative stage (Mengel and Kirkby, 1987). Based on findings that 60-80% of the total uptake of K in Oregon seed crops occurred before 27 April, ie. well before heading, Horneck, Hart and Young (1993a) recommended that potassium be applied between autumn and spring. Under Norwegian conditions, the period between start of growth and heading is usually limited to approximately two months, and a considerable part of the vegetative development therefore has to take place in autumn. With this background it is not surprising that autumn application produced higher seed yields than spring application on heavy soils which are not liable to K leaching.

Both on light and heavy soils, spring input in excess of 40 kg K ha^{-1} often had a negative effect on panicle formation and seed yields (Tables 4 and 5, Fig. 2). Similar results have been reported by Wølner (1971) and Nordestgaard (1990), although at higher rates of K than used in the present experiments. The reasons for these negative effect are not clear, although high concentrations of K may reduce the uptake of other nutrients, notably Mg. Analyses for the concentration of Mg in straw dry matter were only conducted in the last year of experimentation, and the differences which were then found did not coincide with the observed effects on seed yield. However, as the concentration of K in grass dry matter declines sharply after heading, whereas that of Mg remains relatively constant (Horneck *et al.*, 1993 a,b), it cannot be totally rejected that antagonism between the two cations influenced spring growth and thus seed yield. Other hypotheses, perhaps just as likely, are that high inputs of K inhibited the uptake of NH_4^+ at low soil temperatures in the early season, or that Cl^-, because of the application of KCl, had a negative impact on the uptake of NO_3^- (Mengel and Kirkby, 1987).

The high removal of K in straw after spring application of 80 or 120 kg K ha^{-1} on light soils (Fig.3) was clearly due to luxury consumption, as the straw dry matter yield did not increase at rates higher than 40 kg K ha^{-1} (Table 5). The reason why such luxury consumption only occurred on light soils may be that grass species and soil type are confounded, as plant analyses were only accomplished for meadow fescue on a light soil and red fescue and smooth bromegrass on heavy soils. Horneck *et al.* (1992, 1994) found that tall fescue was more liable to luxury consumption than perennial ryegrass, and this may also be the case also for meadow fescue in comparison with red fescue and smooth bromegrass.

In conclusion, the present results indicate that Norwegian grass seed crops should not receive more than 40 kg K ha^{-1}, irrespective of soil K values. At least on heavy soils, K should either be given in autumn or split between autumn and spring. Based on current recommendations for N inputs (Table 2), an optimal solution is probably to use a high PK compound fertilizer in autumn (e.g. Fullgjødsel® (NPK) 18-3-15) or Fullgjødsel® (NPK) 17.5.13) and either pure nitrogen or a low PK compound fertilizer (e.g. Fullgjødsel® (NPK) 25-2-6) in spring. Spring application of Fullgjødsel® (NPK) 21-4-10 seems justified to timothy seed crops which do not receive N in autumn (Aamlid, 1997). In addition to N, P and K, all types of Fullgjødsel® also contain calcium (Ca), magnesium (Mg), sulphur (S) and boron (B) which, at least on some soils, may be warranted in grass seed production.

ACKNOWLEDGEMENTS

Thanks are expressed to Ove Hetland and the farmers' experimental and advisory groups in Hedmark, Aremark-Rakkestad, Buskerud, Vestfold and Aust Agder for excellent field work, Gunnhild Hommen for seed analyses and the laboratory at Holt Research Centre for chemical analyses.

REFERENCES

1. Aamlid, T.S. 1997. Nitrogen and moisture inputs to seed crops of timothy (*Phleum pratense* L.) II. Split application of nitrogen in the seed harvest year. *Journal of Applied Seed Production* 15: 5-16.
2. Brown, K.R. 1980. Seed production in New Zealand ryegrass. II. Effects of N, P and K fertilizers. *New Zealand Journal of Experimental Agriculture* 8: 33-39.
3. Chumbley, C.G. and Jones, J.R. 1973. Nitrogen and potassium for perennial ryegrass seed crops in West Midlands. *Experimental Husbandry* 23: 26-30.
4. Egnér, H., Riehm, K. and Domingo, W.R. 1960. Untersuchungen uber die chemische Bodenanalyse als Grundlage fur die Beurteilung des Nahrstoffzustandes der Boden.*Kungliga Lantbrukshogskolans Annaler* 26: 199-215 (In German).
5. Fulkerson, R.S., Weir, J.R. and McRostie, G.P. 1951. The effect of some fertilizer carriers upon seven grass species. *Scientific Agriculture* 31: 32-38.
6. Hart, J.M., Horneck, D.A., Young III, W.C and Silberstein, T.B. 1991. Potassium for grass seed production. In: Seed Production Research at Oregon State University, 1990 (ed.W. C. Young III), 13-14, USDA-ARS Cooperating. Department of Crop andSoil Science Ext/CrS 83, 4/91.

7. Horneck, D.A., Hart, J.M., Young III, W.C. and Silberstein, T.B. 1992. Potassium for grass seed nutrition. In: Seed Production Research at Oregon State University, 1991 (ed. W.C.Young III), 13-14, USDA-ARS Cooperating. Department of Crop and Soil Science EXT/CrS 89, 4/92.

8. Horneck, D.A., Hart, J.M. and Young III, W.C. 1993a. Uptake of N,P,K and S by five cool-season grass species. In: Seed Production Research at Oregon State University, 1992 (ed.W.C. Young III), 20-23, USDA-ARS Cooperating. Department of Crop and Soil Science EXT/CrS 4/93.

9. Horneck, D.A., Hart, J.M. and Young III, .C. 1993b. Uptake of Ca, Mg, Zn, Cu and B by five cool-season grass species. In: Seed Production Research at Oregon State University, 1992 (ed.W.C. Young III), 23-26, USDA-ARS Cooperating. Department of Crop and Soil Ext/CrS 93, 4/93.

10. Horneck, D.A., Hart, J.M. & Young III, W.C. 1994. Effect of soil K on perennial ryegrass and tall fescue. In: Seed Production Research at Oregon State University, 1993 (ed. W.C. Young III), 14-17, USDA-ARS Cooperating. Department of Crop and Soil Science Ext/CrS 98, 4/94.

11. ISTA 1996. International rules for seed testing. Supplement to *Seed Science and Technology* 24: 1-335.

12. Janovszky, J. 1983. (Effect of cultivation factors on grain yield and yield components in Hungarian brome grass and meadow fescue. III. Effect of cultivation factors on grain yield quantity and quality). *Novenytrmeles* 32: 399-409. (In Hungarian, with English abstract).

13. Lampeter, W. and Schoberlein, W. 1969. Die Vorratsdungung mit P and K im Samenbau verschiedener Futtergraser. *Saat-und Pflanzgut* 10: 160-163. (In German).

14. Lunnan, T. 1993. Grass yield response to potassium fertilization on mineral soils in the inland of southern Norway. *Norwegian Journal of Agricultural Sciences* 7: 345-357.

15. Mengel, K. and Kirkby, E.A. 1987. Principles of Plant Nutrition. 4th Edition. International Potash Institute, Bern, Switzerland, 687 pp.

16. Nordestgaard, A. 1990 (Phosphorus, potassium and pH-levels with seed production of ryegrass (*Lolium perenne*) and meadow fescue (*Festuca pratensis*). *Tidsskift for Planteavl* 94: 449-455. (In Danish, with English abstract).

17. Petersen, M. 1981. Groesploener – Principper and Funktioner. Dahnfeldt, Odense, Denmark. 362 pp. (In Danish).

18. Reitemeier, R.F. 1951. Soil potassium. *Advances in Agronomy* 3: 113-164.

19. Rolston, M.P., Rowarth, J.S., Young III, W.C. and Mueller-Warrant, G.W. 1997. Grass seed crop management. In: Forage Seed Production. 1. Temperate Species (ed. D.T. Fairey and J.G. Hampton), 105-126. CAB International, Wallingford.

20. SAS Institute 1990. SAS/STAT User's Guide. Version 6, Fourth edition. 890 s.

21. Semb, G. and Oien, A. 1961. Investigations on the content of readily available and acid-soluble potassium in various soils and in different layers in soil profiles. *Meldinger fra Norges landbrukshogskole* 38(4): 1-19.

22. Svensson, K. 1994. (Experiences from collecting data from seedgrowers). In: Froproduktion. NJF-seminarium nr 241, 28-30 June 1994. Jokioinen, Finland. (ed. O. Niemelainen and E.Regardh), 169-172, NJF-Utredning/ Rapport nr.97. Nordiska Jordbruksforskars Forening. (In Danish, with English abstract).

23. Wolner, K. 1971. (Growth, development and seed production in timothy (*Phleum pratense*) and meadow fescue (*Festuca pratensis* L.) and effects of fertilizer and some environmental factors on these characters). Felleskjopets forsoks- og stamsaedgard, melding nr 15. (In Norwegian, with English abstract).