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Nitrogen fertilization of grass seed crops as related to soil mineral nitrogen

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Abstract

Field experiments were carried out with *Lolium perenne*, *Poa pratensis* and *Festuca rubra* seed crops from 1978 to 1984 to determine the relationship between the level of soil mineral nitrogen present in early spring and the economically optimum application rate of nitrogen fertilizer. The effect of splitting the spring dressing and the influence of autumn dressings were also studied. In *L. perenne* the optimum spring rates appeared to be linearly related to mineral nitrogen in the 0-90 cm soil layers according to the function 164-0.6 soil mineral N (kg ha^{-1}).

No such relationship was found for *P. pratensis* and *F. rubra*. The mean economically optimum spring nitrogen rates were 110 kg ha^{-1} for *P. pratensis* and 84 kg ha^{-1} for *F. rubra*. Most *P. pratensis* crops yielded highest at an autumn nitrogen dressing of 60 kg ha^{-1}. The corresponding optimum dressing for *F. rubra* was 30 kg ha^{-1}. Autumn dressing had no effect on *L. perenne* if the spring fertilization was near the optimum or higher. Splitting the spring dressing stimulated vegetative regrowth and gave yields that were lower or, at best, equal to those obtained with early single dressings. Seed yield responses to fertilization were mainly related to the number of inflorescences produced and to a lesser degree to the weight of seed per inflorescence. The apparent stability of average seed weight is discussed.

Introduction

Until 1986 the recommendations for spring nitrogen fertilizer for grass seed crops in the Netherlands were: 130 kg ha^{-1} nitrogen for *Lolium perenne*, 90 kg ha^{-1} for *Poa pratensis* and 70 kg ha^{-1} for *Festuca rubra* (ssp. *commutata*). In practice, these gui-

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delines were adapted according to soil type, preceding crop and cultivar. In the last decade the recommendations for cereals, sugar beet and potatoes are based on the relation between soil mineral nitrogen in early spring (Nmin) and the economically optimum rate of nitrogen fertilizer (Ris et al., 1981; Neeteson, 1982). In the research described in this paper the applicability of the Nmin method for grass seed crops was studied.

In *P. pratensis* and *F. rubra* inflorescence production greatly depends on vegetative growth before winter (Meijer, 1984; Nordestgaard, 1987); therefore in all trials with these species, spring fertilizer rates were combined with autumn dressing rates. In *L. perenne*, tillers emerging in spring are able to compensate for weak crop development in autumn, thus yield depends less on autumn growth (Foster, 1969; Hill & Watkin, 1975). Therefore, the influence of autumn fertilization was examined in only four of the experiments with that species.

The favourable results obtained with wheat crops have led to the spring dressing occasionally being split for grass seed crops. Most often, splitting has been reported to have negative effects (Hebblethwaite & Ivins, 1978; Nordestgaard, 1983) but positive results have also been recorded (Simon, 1960). Therefore, in three experiments with *L. perenne* the effects of split dressing were also studied.

Materials and methods

Field experiments were carried out during 1978-1984 in four locations in the Netherlands on fertile marine clay soils. In 12 experiments with perennial ryegrass (*Lolium perenne L.*), nitrogen fertilizer was applied in spring at 6 rates: 60-90-120-150-180-210 kg ha^{-1} (Table 1). According to normal practice in 8 of these trials an autumn dressing of 30 kg ha^{-1} was applied. In addition, in 4 experiments the effect of autumn fertilization was studied: the spring rates were combined with 0 and 45 kg ha^{-1} in the preceding autumn. In 3 experiments the effect of splitting the spring dressing was examined: about two weeks after first heading, a second dressing of 30 or 60 kg ha^{-1} nitrogen was applied above the 60, 90 and 120 early dressing rates. In 13 experiments with smooth stalked meadowgrass (*Poa pratensis L.*) and in 10 with red fescue (*Festuca rubra L.* ssp. *commutata*) the effect of spring fertilization (*P. pratensis* 60-90-120-150 kg ha^{-1}; *F. rubra* 30-60-90-120 kg ha^{-1}) was examined at three levels of autumn fertilization (30-60-90 kg ha^{-1}). In the experiment with *L. perenne*, 7 cultivars (Premo, Majestic, Cropper, Barlenna, Hunter, Barenza, Manhattan) were included; with *P. pratensis* 5 cultivars (Aquila, Parade, Baron, Entopper, Geronimo) and with *F. rubra* 2 cultivars (Dawson, Koket). Most experiments were carried out on first-year crops; 4 trials with *P. pratensis*, one with *L. perenne* and also one with *F. rubra* were with second-year crops.

At the end of January, or as early thereafter as soil conditions allowed and before fertilizer application, mineral nitrogen (i.e. NO_3- and NH_4-nitrogen after extraction with 1 mol l^{-1} NaCl) was determined in 3 soil layers, 0-30, 30-60 and 60-90 cm, according to Ris et al., 1981. Based on results of Nordestgaard (1979, 1980) the timing of the application of the spring dressings was aimed at the second half of February, about two weeks before the double ridge stage of the first reproductive tillers.

Table 1. Summary of experiments. The treatments are indicated by the different nitrogen rates applied in autumn, in early spring and after heading (kg ha^{-1}).

Number of experiments	Nitrogen dressings			Number of treatments
	autumn	spring	heading	
Lolium perenne				
5	30	60-90-120-150-180-210	0	6
4	0-45	60-90-120-150-180-210	0	12
3	30	60-90-120-150-180-210	0	12
		60-90-120	30-60	
Poa pratensis				
13	30-90-60	60-90-120-150	0	12
Festuca rubra				
10	30-60-90	30-60-90-120	0	12

To avoid salt damage, dressings above 90 kg ha^{-1} were split, but then the supplementary fertilizer was applied before mid-March. Soil mineral nitrogen, aboveground crop mass, nitrogen content of the crop and nitrate content of the leaves were determined at regular intervals in two experiments for each of the species.

All treatments were replicated four times and data on seed production were obtained by harvesting 21 m^2 per plot. Inflorescence numbers were assessed at harvest from 0.25 m^2 per plot for most crops. In the experiments with split dressings, secondary vegetative growth was scored on a 0-10 scale. The relationship between nitrogen dressings in spring and seed yields was assessed by hand-drawn response curves for each trial and for all nitrogen levels applied in autumn. From these curves the economically optimum application rates of fertilizer-N, i.e. the minimum amounts of fertilizer nitrogen needed for maximum financial yields (Ris et al., 1981) were derived, by assuming a price ratio of fertilizer-N to grass seed of 0.5 for *L. perenne* and 0.4 for *P. pratensis* and *F. rubra*. For each species the linear relationship between these optimum fertilizer rates and the measured amount of mineral nitrogen (Nmin) in the 0-60 cm and 0-90 cm soil layers was then ascertained. With *L. perenne* the 6 spring fertilizer rates allowed to determine optimum fertilizer rates also from calculated quadratic or exponential response curves (Neeteson & Wadman, 1987). Only 4 spring rates in the experiments with *P. pratensis* and *F. rubra* were considered as being too few for reliable calculations.

Results and discussion

Lolium perenne

An autumn dressing boosted seed yields if the spring dressing was too low but, when spring rates were near the optimum, on average no effect was found (Table 2). Two

Table 2. Effect of nitrogen fertilization in autumn and spring on seed production (kg ha^{-1}) of *Lolium perenne*. Mean of four experiments in 1981 and 1982.

Autumn nitrogen (kg ha^{-1})	Spring nitrogen (kg ha^{-1})					
	60	90	120	150	180	210
0	1108	1248	1265	1360	1358	1350
45	1240	1305	1343	1370	1378	1330

crops out of four developed weakly in autumn because of late sowing and growth under a dense cover crop and benefitted most from the autumn dressing. Nordestgaard (1977) found from 14 experiments with 3 cultivars that differences between no autumn nitrogen and a dressing of 30 kg ha^{-1} were negligible; 60 kg ha^{-1} was always too high for optimum yields. Hill (1972) found a strong positive effect of 50 kg ha^{-1} autumn nitrogen. However, the short and dry growing season in New Zealand may have been responsible for growth and nitrogen uptake being more important in autumn. In Hill's experiment also grazing by sheep until floral initiation may have interfered with the fertilization treatments.

In 3 out of our 4 experiments with nitrogen dressing in autumn and spring, no interaction was found and thus 15 independent response curves on spring fertilization rates were obtained. The economically optimum rates derived from the hand-drawn curves appeared to be linearly related to the mineral nitrogen in the 0-90 cm soil layers (Fig. 1). According to this highly significant relationship ($r = -0.86$, $P < 0.0001$) the contribution of soil nitrogen is best accounted for by applying fertilizer N at a rate of 164-0.6 Nmin kg ha^{-1}. With nitrogen in the 0-60 cm soil layer the correlation appeared to be less consistent ($r = -0.64$, $P < 0.01$).

The response curves were also calculated on the basis of quadratic or exponential equations, according to Neeteson & Wadman (1987). The calculated optima of two experiments fell outside the range of applied fertilizer rates and were therefore omitted. The remaining 13 optima all lay within the 95 % confidence interval, but that confidence interval was often relatively wide and in 7 experiments it comprised the whole range of nitrogen rates tested. The calculated optima were weakly and not significantly related to Nmin ($r = -0.50$, $0.05 < P < 0.10$). These results suggest that for our trials hand-drawing of the curves should be preferred, although that method is susceptible to subjectivity and does not allow to state the reliability of the optima.

In this series of trials, applying spring fertilizer according to the function 164-0.6 Nmin would, on average, have resulted in a spring dressing of 127 kg ha^{-1}. Thus, compared with the current recommendation of 130 kg ha^{-1} (see 'Introduction') the Nmin method did not lead to substantial saving of fertilizer nitrogen. From the response curves it was derived that, on average, the calculated optimum spring rates would have boosted seed yields by only 9 kg ha^{-1} compared with the fixed rate of 130 kg N ha^{-1}. The costs of the soil analysis required for the Nmin method are therefore only justifiable if the soil is likely to have a high level of mineral nitrogen.

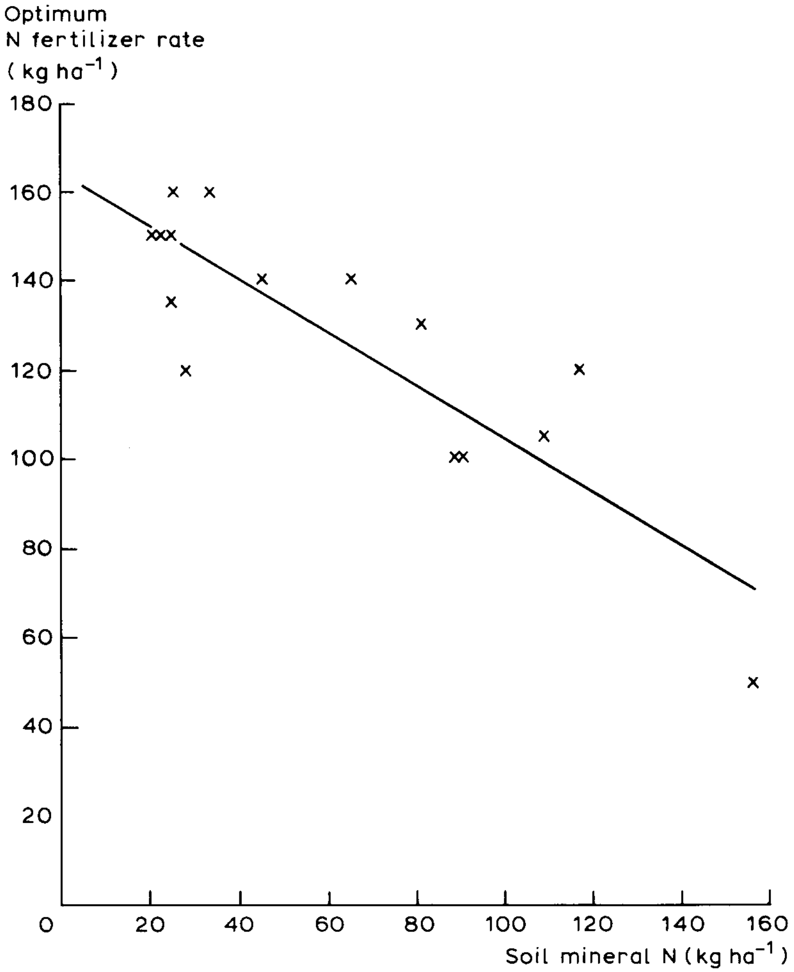

Fig. 1. The relationship between mineral nitrogen in the 0-90 cm soil layer in early spring and the economically optimum application rate of spring fertilizer nitrogen. 15 experiments in *Lolium perenne*, 1978-1984. $y = 164-0.6x$; $r = -0.86$; $P < 0.0001$.

From 11 experiments, Nordestgaard (1980) found an optimum of 135 kg ha^{-1} and because soil mineral nitrogen is low under the prevailing cereals/grass rotation in Denmark, this result agrees well with ours. Hebblethwaite & Ivins (1977) found optimum levels of applied N ranging from 80 to 120 kg ha^{-1} and suggested that the lowest levels were associated with high levels of available soil N. Hampton et al. (1983) achieved optimum seed yields at much lower fertilizer rates: 40-80 kg ha^{-1}. These authors related the failure to increase seed yield at high N rates to strong vegetative tillering in their experiments. Their timing of spring fertilization at spikelet initiation stage may have been relatively late. In our experiments, vegetative tillering

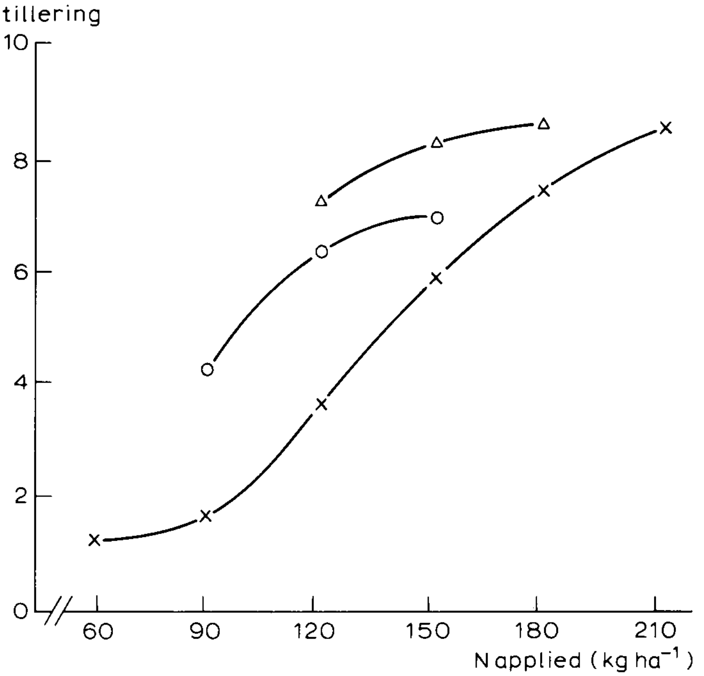

Fig. 2. The effect of fertilization rate and split dressing of nitrogen in spring on secondary vegetative growth at harvest. *Lolium perenne*, 1978. Tillering scored as: 1 = low and 10 = high number. × = single dressing; split dressing with ○ = 30 and △ = 60 kg ha^{-1} applied late.

appeared to be strongly related to the nitrogen rate, and nitrogen applied late gave an extra boost (Fig. 2). According to Hampton et al. (1983) and Clemence & Hebblethwaite (1984), secondary vegetative tillers compete for assimilates with seeds. Higher vegetative tillering probably explains why in our experiments split dressing was found to produce poorer results or, at best, results equal to the single early dressings at the same total rate (Table 3). Similar results with splitting are reported

Table 3. The effect of single and split dressing of nitrogen (kg ha^{-1}) on seed yield (kg ha^{-1}) of *Lolium perenne*, 1978.

Dressing in February (kg ha^{-1})	Dressing in May (kg ha^{-1})		
	0	30	60
60	1730	1780	1680
90	1860	1870	1730
120	1900	1820	1910
150	1900	–	–
180	1740	–	–
210	1750	–	–

by Nordestgaard (1980) and Hebblethwaite & Ivins (1978). Simon (1960) reported increased seed yields by applying N at 30 or 60 kg ha^{-1} at the elongation stage. His trial was carried out in 1959, which appeared to be a very dry year. In our experiments it was observed that secondary vegetative tillering depends greatly on moisture. In a dry season or in a dry climate, vegetative tillering and its negative effects on seed production are probably much reduced and therefore the beneficial effects of late applied nitrogen dominate.

Poa pratensis and Festuca rubra

In some of the experiments, autumn dressing had a marked effect on seed yield, but on average and at higher spring rates the level of nitrogen in autumn had little effect (Fig. 3). In 8 out of 13 experiments with *P. pratensis* the highest seed yields were achieved at nitrogen at 60 kg ha^{-1} in autumn. With most *F. rubra* crops the optimum autumn dressing appeared to be lower: 30 kg ha^{-1} in 6 out of 10 experiments. In both species a tendency of poor stands, with few and small tillers per unit area, was found to yield better at a higher autumn fertilizer rate. Nordestgaard & Larsen (1971) and Larsen & Nordestgaard (1969) suggest that increased spring rates can greatly compensate for lower autumn dressings. In most of our trials such relation-

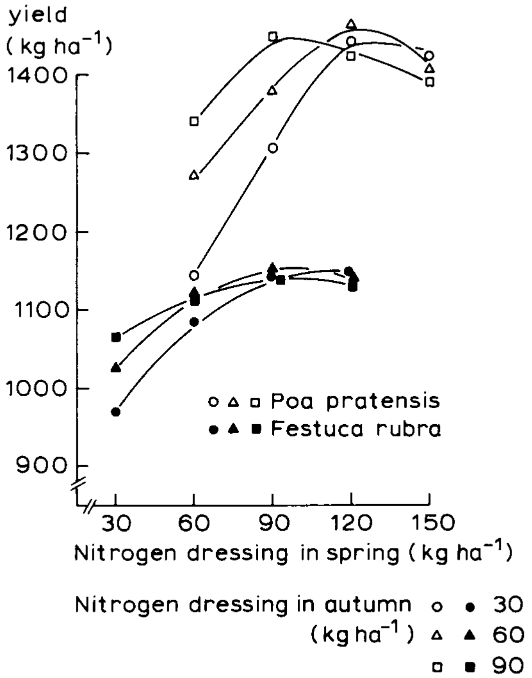

Fig. 3. The effect of nitrogen dressing in autumn and in spring (kg ha^{-1}) on seed yield (kg ha^{-1}) of *Poa pratensis* (13 experiments, 1979-1984) and *Festuca rubra* (10 experiments, 1978-1984).

ship was not found as in 9 out of 13 experiments with *P. pratensis* and 8 out of 10 experiments with *F. rubra* the interaction between autumn and spring dressings was not significant.

For both species, no significant relationship was found between the amounts of soil mineral nitrogen and the optimum spring fertilizer rates, either at the best autumn rates per trial, or when the response curves for each autumn dressing were considered separately. Apparently, soil nitrogen explains a minor part of the variation, and many other factors such as temperature and precipitation during seed formation, lodging, synchronous ripening and vegetative growth may together be more influential. A second reason for the absence of a clear relationship between Nmin and optimum fertilizer rates may be that the range of soil nitrogen data was narrow. In the 0-90 cm soil layers with *P. pratensis* 8 to 56 and with *F. rubra* 12 to 48 kg ha^{-1} nitrogen was found. The low soil nitrogen status can be attributed to the preceding crop: most of these *P. pratensis* and *F. rubra* crops were grown after winter wheat, which leaves very low amounts of nitrogen in the soil profile (Neeteson et al., 1987).

Our experiments indicate that the optimum spring fertilizer rate for *P. pratensis* and *F. rubra* cannot be derived from the soil nitrogen status. Other methods that take crop growth and mineralization in spring into account (Neeteson et al., 1987) are not applicable because these species have to be fertilized early after winter (Nordestgaard, 1983; 1985). Therefore the optimum spring rates are derived per trial at the highest yielding autumn dressing. The average for all trials was 110 kg ha^{-1} for *P. pratensis* and 84 kg ha^{-1} for *F. rubra*. For *F. rubra* this agrees well with the results from literature, but the figure found for *P. pratensis* is substantially higher (Nordestgaard, 1980). In our trials with *P. pratensis*, 7 out of 13 were carried out with pasture types bred for vigorous growth and high forage production. The remaining 6 trials were conducted with cultivars bred for amenity purposes. The latter types have been selected for high tillering and low production. On average, the optimum spring rate for the pasture types was 94 kg ha^{-1} against 133 kg ha^{-1} for the amenity types. Although these experiments do not allow the two types of cultivars to be compared, the figures indicate that different spring fertilizer recommendations may be needed for pasture and amenity types of *P. pratensis*.

Seed yield components

In our experiments with three species, the seed yield responses to fertilization were mainly related to the number of inflorescences produced and to a lesser degree to the production of seed per inflorescence (Tables 4 and 5). With *L. perenne* the differences in seed production per inflorescence were associated with seed number and with average seed weight. In *P. pratensis* and *F. rubra* the average seed weight was almost unaffected by fertilization. In the literature it is reported that the influences of nitrogen fertilization vary between mainly affecting inflorescence numbers, seeds per inflorescence, or affecting both. In our trials too, the average seed weight was most often remarkably stable (Hebblethwaite & Ivins, 1977; Hebblethwaite et al., 1978; Nordestgaard, 1980; Hampton et al., 1983). It has been stated

Table 4. The effect of nitrogen dressed in spring (kg ha^{-1}) on seed yield and yield components of *Lolium perenne*. Mean of 11 experiments, 1978-1983.

	Nitrogen in spring (kg ha^{-1})					
	60	90	120	150	180	210
Seed yield	100 (1300 kg ha^{-1})	106.9	111.5	113.8	113.1	111.5
Inflorescences	100 (2220 m^{-2})	106.3	107.7	108.6	109.5	106.8
1000-seed weight	100 (1.62 g)	100.6	102.5	101.9	101.9	102.5
Seed weight per ear[1]	100 (58 mg)	101.7	105.2	105.2	105.2	105.2
Seeds per ear[1]	100 (36)	100.0	102.7	102.7	102.7	102.7

[1] Calculated.

Table 5. The effect of nitrogen dressed in spring on seed yield and yield components of *Poa pratensis* (8 experiments, 1979-1984) and *Festuca rubra* (7 experiments, 1978-1984). Nitrogen in autumn = 60 kg ha^{-1}.

	Nitrogen in spring (kg ha^{-1})				
	30	60	90	120	150
Poa pratensis					
Seed yield		100 (1367 kg ha^{-1})	108.3	117.0	111.8
Inflorescences		100 (2460 m^{-2})	110.4	109.3	106.5
1000-seed weight		100 (0.373 g)	100.5	99.7	98.7
Seed weight per ear[1]		100 (55.6 g)	98.0	107.0	104.9
Seeds per ear[1]		100 (149)	98.7	108.0	106.7
Festuca rubra					
Seed yield	100 (1126 kg ha^{-1})	111.9	113.6	113.0	
Inflorescences	100 (2930 m^{-2})	111.4	107.5	100.2	
1000-seed weight	100 (0.830 g)	99.5	100.8	101.6	
Seed weight per ear[1]	100 (38.4 g)	99.7	105.7	112.8	
Seeds per ear[1]	100 (46)	100.0	106.5	110.9	

[1] Calculated.

that in well-developed crops many more fertile tillers are produced than ultimately flower. Actual inflorescence production is mainly determined by the increasing competition for light and assimilates during the stem elongation phase (Wright, 1978; Meijer, 1984). The increased influorescence production at optimum dressings in our experiments is therefore attributable to the better survival of reproductive tillers that mainly elongated later. But given that later elongating reproductive tillers will probably produce smaller heads and less seed (Anslow, 1964; Ryle, 1964), the higher seed production per head at higher fertilizer rates in our experiments (Tables 4 and 5) is striking. Increased seed numbers per inflorescence at higher fertilization rates can result from increased floret numbers per spikelet and per head (Hebblethwaite & Ivins, 1977; Hampton et al., 1983) and from better seed filling because of delayed senescence of the photosynthetically active plant parts (Hampton et al., 1983). The latter can only explain higher seed production per inflorescence if seed setting and filling are not impeded by severe lodging and excessive vegetative tiller growth (Hebblethwaite & Ivins, 1977; Burbidge et al., 1978). In most of our experiments lodging was severe at the highest fertilizer rates but secondary growth was relatively unimportant. This suggests that lodging does not always seriously hamper floret fertilization and seed filling. Hampton et al. (1983) have also suggested that secondary growth stresses seed filling more than lodging does. In our experiments, in all years and at all nitrogen rates far less vegetative than fertile tillers were found at harvest, probably because nitrogen was applied before the first tillers had reached the double-ridge stage. Early fertilization has been shown to reduce secondary vegetative tillering (Hebblethwaite & Ivins, 1978; Nordestgaard, 1983).

Improved seed filling does not necessarily result in higher 1000-seed weight. At harvest often about half of the set seed is recovered, the remaining half being insufficiently filled or unripe and removed by cleaning (Meijer, 1985). At higher nitrogen rates the greater proportion of late inflorescences increases the proportion of late developing and therefore light seeds at harvest. These seeds will depress average seed weight. An apparently stable seed weight could therefore actually be the expression of a balance between favourable and unfavourable influences.

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