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Effects of nitrogen on accumulation and partitioning of dry matter and nitrogen of vegetables. 2. Leek

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Abstract

Information about the nitrogen demand and response of leek (*Allium porrum* L.) is scarce, but relevant for optimisation of nitrogen fertilisation strategies. The purpose of the current study was to analyse the dynamics of accumulation of dry matter and nitrogen in leek. Therefore four experiments were carried out with different amounts and different dates of application of nitrogen. Observations included frequent measurements of dry matter and nitrogen accumulation of leaf blades, leaf sheaths and, if present, scape.

Both the amount of nitrogen applied and the time of application affected the total accumulation of dry matter and nitrogen in the plant. The relative partitioning rates of dry matter increase to the shaft were affected in such a way that the final harvest indices for dry matter (which ranged from 0.32–0.53) were significantly lower at higher amounts of nitrogen applied. The final harvest indices for nitrogen ranged from 0.21–0.35 and were not significantly affected by amount or timing of fertiliser applications. The total nitrogen concentrations of leaf blades and leaf sheaths decreased with increasing leaf age. Average nitrate nitrogen concentrations over all plant parts were always below 0.4%.

Key words: Leek, *Allium porrum* L., nitrogen nutrition, dry matter production, dry matter distribution, nitrogen uptake, nitrogen concentration, nitrogen distribution

Introduction

Leek is a biennial plant. During the vegetative phase, in the first year, growth of leaf blades, leaf sheaths and roots takes place. Usually the scape develops during the second year, but sometimes scapes are observed at harvest in the first year, which are only visible after dissecting the plants (Dragland, 1972).

Information about accumulation and partitioning of fresh and dry matter and nitrogen at harvest in relation to nitrogen fertilisation is scarce, just as information on the dynamics of these characteristics during crop growth. Such information, however, is important for a proper understanding of the nitrogen requirement and for fine-tuning the nitrogen fertilisation to the demand of the crop, and to minimise nitrogen

losses to the environment. Such information is also indispensable for the development of simulation models on plant growth and the use of inputs. Therefore this study aims to acquire this information.

The potential dry matter yield of leek in Western Europe is around 1200 g m^{-2}, when early planted, well-watered and well-fertilised (Brewster, 1994). The highest yields are usually achieved with about 60 plants m^{-2}, but to produce large leeks, densities of 15–20 plants m^{-2} are used. The optimal total nitrogen supply (mineral nitrogen in soil layer 0–30 cm plus fertiliser nitrogen) is about 270 kg ha^{-1} under Dutch circumstances.

Based on Experiments 1, 3 and 4 of the current study, Biemond (1995) described effects of nitrogen on leaf development and growth of leek. More nitrogen increased the total green leaf area by increasing the area of individual leaves. The rate of leaf appearance, the rate of leaf senescence and therefore the number of green leaves were not affected. Larger individual leaves resulted from larger leaf expansion rates, the duration of leaf expansion being unaffected. In this paper, the plant dry matter and nitrogen accumulation and the relative partitioning of dry matter and nitrogen over leaf blades, leaf sheaths and other organs are analysed.

Materials and methods

Two glasshouse experiments (Experiments 1 and 2) and two field experiments (Experiments 3 and 4) are described. A brief description of the design of Experiments 1, 3 and 4 suffices here, because details were given by Biemond (1995). Experiment 2 was not described before.

Plant culture – glasshouse

Young, pencil-thick leek plants (cv. Albana; in Experiment 1 with five and in Experiment 2 with six leaves) were planted (Experiment 1: 1 May 1991; Experiment 2: 30 September 1992) in 20–l pots (containing sand, free from organic matter), four plants per pot in Experiment 1 and five plants per pot in Experiment 2. The glasshouse, in which the pots were placed, was set to maintain a day (12 h) temperature of 18 °C (Experiment 1) or 20 °C (Experiment 2) and a night temperature of 12 °C (both experiments). On sunny days, the capacity of the cooling system of the glasshouse was insufficient, which resulted in temperatures of 2 or 3 °C above the set temperatures. Natural light was supplemented with 400 Watt Philips SON-AGRO-T lamps at a density of 0.7 lamps m^{-2}. With a pot density of 5.0 m^{-2} in Experiment 1 and 4.0 pots m^{-2} in Experiment 2, a similar plant density of 20 plants m^{-2} was attained in both experiments.

Plant culture – field

Experiments 3 and 4 were conducted on a sandy soil with about 3% organic matter. Plants of the same cultivar and plant size as in Experiment 1 were planted about 10

cm deep in rows, with a row-spacing of 25 cm and a distance between plants within the row of 20 cm, resulting in a plant density of 20 plants m^{-2}. Experiment 3 was planted on 12 May 1992; Experiment 4 on 7 May 1993. Irrigation was applied immediately after planting and later on whenever necessary.

Treatments and experimental design

Each glasshouse experiment had four different treatments, each field experiment three different treatments (see Figure 1), consisting of different total amounts and dates of application of nitrogen. In Experiment 1 treatments were: N(1.8/2): 1.8 g N per pot, supplied in two splits of 0.9 g; N(1.8/6): 1.8 g N per pot (six equal splits); N(5.4/2): 5.4 g N per pot (two equal splits); N(5.4/6): 5.4 g N per pot (six equal splits). In Experiment 2 treatments were: N(1.0): 1.0 g N per pot, with nitrogen limitation throughout the experiment; N(2.4;E(arly)): 2.4 g N per pot, with non-limiting supply in the early stages of growth and limiting supply later; N(2.4;L(ate)): 2.4 g N per pot, with limiting supply in the early stages of growth and non-limiting supply later; N(5.9): 5.9 g N per pot; non-limiting supply throughout the experiment. In both glasshouse experiments, other nutrients were supplied in equal amounts to all

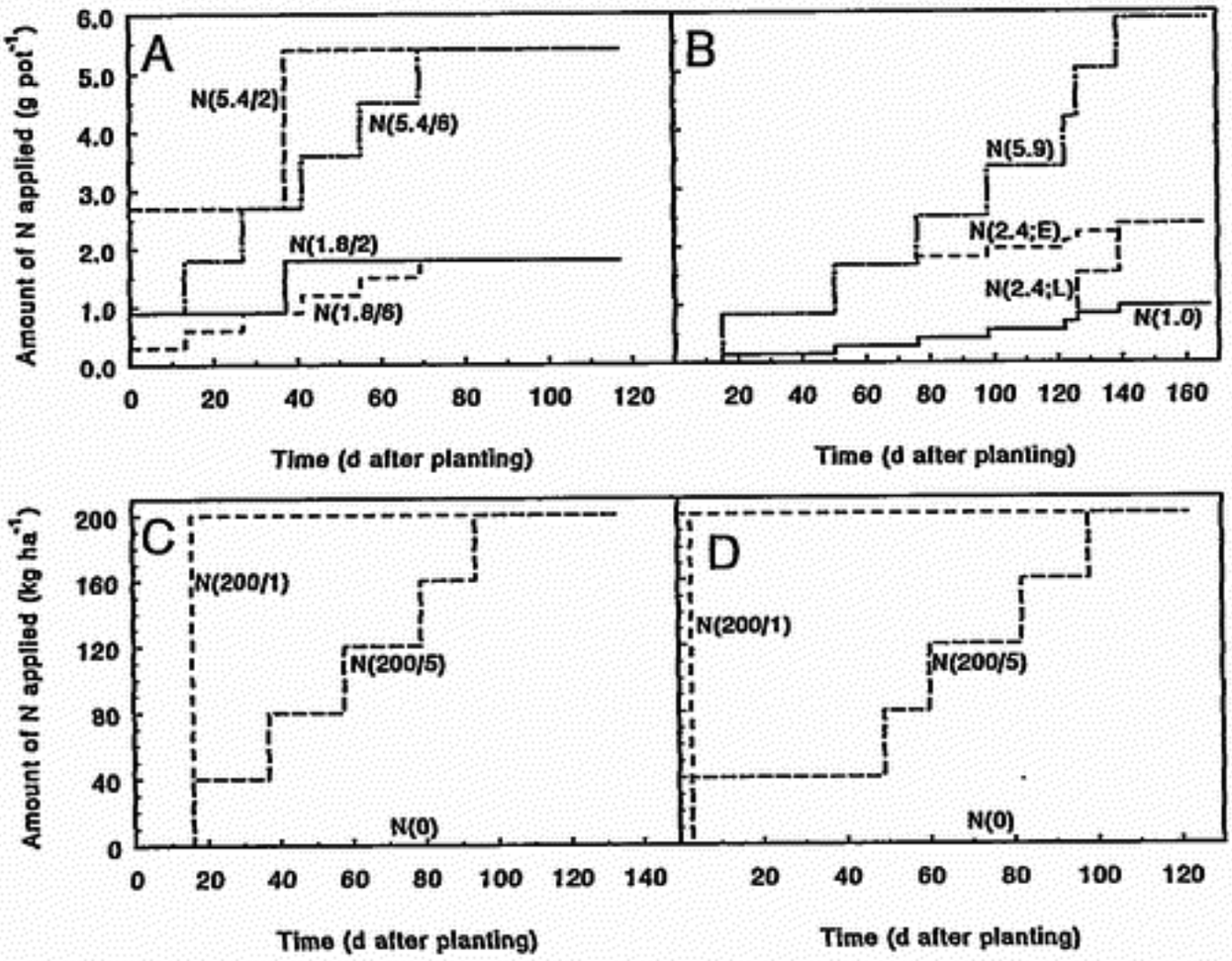

Figure 1. Accumulated amounts of nitrogen (in g pot^{-1} or kg ha^{-1}), applied to the different treatments of Experiment 1 (A), Experiment 2 (B), Experiment 3 (C) and Experiment 4 (D).

treatments. Nitrogen supply for treatments with nitrogen stress was based on a comparison of actual growth (which was regularly measured at destructive harvests) with growth and nitrogen uptake in Experiments 1 and 3. The experiments were laid out in a randomised complete block design, Experiment 1 with five blocks and Experiment 2 with four blocks. In the statistical analyses of Experiment 1 the four treatments were split into two factors, viz. amount of nitrogen (1.8 vs 5.4 g per pot) and number of applications (two vs six splits).

Experiments 3 and 4 had the same three treatments: N(0): no application of fertiliser nitrogen; N(200/1): 200 kg N per ha, applied shortly after planting; N(200/5): 200 kg N per ha, applied in five splits of 40 kg. At planting 77 kg ha^{-1} mineral N was available in the soil layer 0–60 cm in Experiment 3; this was 75 kg ha^{-1} for Experiment 4. These two experiments were laid out in a split-plot design with nitrogen treatment as main factor and harvest date (see *Sampling and plant analyses*) as split factor. Both experiments had four blocks. Statistical analyses of each experiment were made on separate data for each harvest, since we were interested in differences among treatments and not specifically among harvests. The significance of differences is assessed with an LSD-test (P=0.05), following an analysis of variance.

Sampling and plant analyses

Destructive analyses of plants were carried out several times: in Experiment 1 on six occasions between 26 and 117 DAP (days after planting), in Experiment 2 on six occasions between 54 and 167 DAP, in Experiment 3 on six occasions between 35 and 134 DAP and in Experiment 4 on five occasions between 38 and 122 DAP. In Experiments 1 and 2 on each sampling date one pot per treatment was used from each block. In Experiments 3 and 4 1.0 m^2 per treatment was harvested from each block on each sampling date.

The measurements included leaf area, and fresh and dry weights of leaf blades, leaf sheaths and scape (when present). In the growth analysis, each leaf blade and each leaf sheath were taken separately in Experiment 1, but in Experiments 2, 3 and 4 two successive leaf blades or leaf sheaths were pooled. Dead leaf blades and leaf sheaths were collected in Experiments 2, 3 and 4, although this was especially difficult in Experiment 4, because of the wet growing season. In this paper the shaft is defined as being the total of living leaf sheaths. (The marketable part comprises mainly the shaft.) With the term 'leaf number' always the leaf insertion number is meant; otherwise the term 'number of leaves' is used. Leaf blade number increases with decreasing age. At harvests, leaf blade numbers could be determined exactly because several leaves were marked with a coloured thread before.

Dried samples were ground. To reduce the number of samples for chemical analysis, the samples from the replicates of all harvests, except the final ones, were pooled and mixed thoroughly. One subsample from this pooled sample was subsequently analysed for total nitrogen and nitrate (Biemond & Vos, 1992). At the final harvests the samples from the individual replicates were analysed separately, after leaf blades and leaf sheaths from all nodes of one plant were pooled.

Results

Accumulation of dry matter and nitrogen

Figure 2 shows the relations between total dry matter production, shaft dry matter production, total nitrogen uptake and shaft nitrogen uptake at the final harvest of each experiment; each datum point represents one of the treatments. There was a close relation between amount of nitrogen applied and nitrogen uptake. The first quadrant shows large differences among experiments in dry matter production and nitrogen uptake across experiments. These differences will partly have resulted from differences in the amount of incident radiation, which increased in the sequence Experiment 2 – Experiment 1 – Experiment 4 – Experiment 3 (data not shown). The relative differences in total dry matter production within one experiment were much smaller than the relative differences in total nitrogen uptake, resulting in large differences in total nitrogen concentration. In the second and third quadrant large differences existed between experiments as a result of large differences in absolute dry matter yield. The fourth quadrant, however, shows that the relations between total and shaft nitrogen were fairly conservative. A linear regression line for each experiment would practically pass the origin, indicating that harvest indices for nitrogen were fairly constant over ranges of dry matter production and nitrogen uptake.

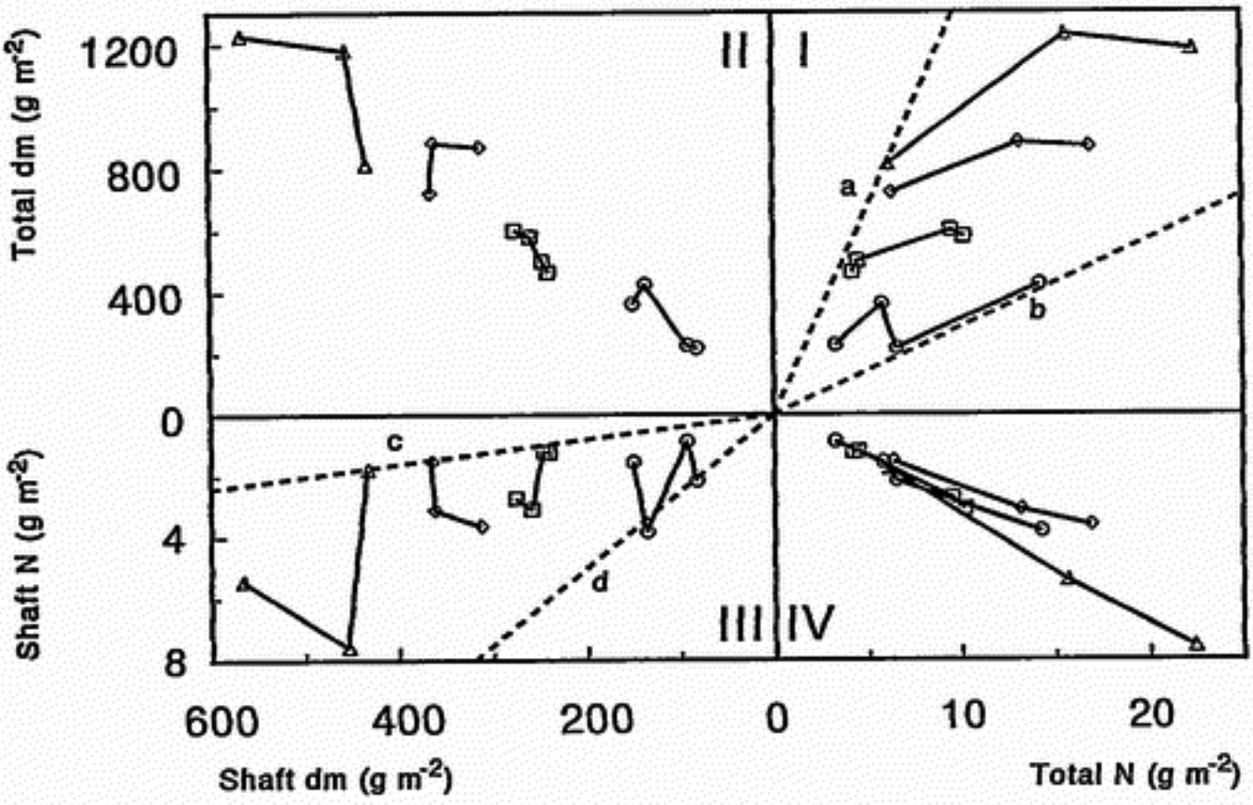

Figure 2. Relations between total dry matter production (Total dm), shaft dry matter production (Shaft dm), total nitrogen uptake (Total N) and shaft nitrogen uptake (Shaft N) at the final harvest of each experiment. All variables are in g m^{-2}. The dotted lines in quadrants I and III represent 0.75 ('a'), 3.5 ('b'), 0.4 ('c') and 2.5 ('d') % nitrogen in the total or shaft dry matter. (□) Experiment 1; (○) Experiment 2; (△) Experiment 3; (◇) Experiment 4.

Partitioning of dry matter to different plant organs

The harvest indices for dry matter are calculated as the amount of dry matter in the living leaf sheaths (= the shaft), divided by the total amount of dry matter. At the first intermediate harvest of each experiment harvest indices were between 0.35 and 0.50. Except in Experiment 2 (carried out in winter) the harvest indices increased slightly with time: final values are shown in Table 1. In Experiment 1 the final harvest indices for dry matter were not significantly affected by treatments, but in Experiments 2–4 applying more nitrogen decreased the final harvest indices for dry matter significantly. Nitrogen stimulated leaf blade growth more than it stimulated leaf sheath growth. The lower harvest indices for dry matter in N(200/5) compared to N(200/1) of Experiments 3 and 4 can be explained as a result of a better nitrogen availability in N(200/5): although the total amount of nitrogen applied was the same, at the end of both experiments more nitrogen was available for the N(200/5) in the upper 30 cm of the soil (data not shown), where most roots are found.

The relative partitioning rates of dry matter increase to leaf blades (including dead ones), leaf sheaths (including dead ones) and scape are calculated from the increase in dry matter of a particular plant part over the period of time between harvests, divided by the total increase of dry matter in the same period. Figures 3A, B and C show the relative partitioning rates in Experiment 3, which decreased for leaf blades and increased for leaf sheaths and scapes during the second half of the growing season. Similar patterns (not shown) were observed in Experiment 4; they indicate that the rate of storage of dry matter in leaf sheaths increased at the end of the growing season, probably because leek is a biennial. The relatively high final partitioning rate to scapes in Experiment 1 (about 0.30) was caused by the unusually high number of scapes observed in this experiment.

Partitioning of nitrogen to different plant organs

The harvest index for nitrogen was always lower than the harvest index for dry matter due to the lower than average nitrogen concentration of the shaft. The final harvest indices for nitrogen (Table 1) were not affected by treatments, indicating negligible effects of nitrogen nutrition on the nitrogen partitioning. This is also illustrated for Experiment 3 in Figures 3D, E and F: the relative partitioning rates of nitrogen increase to leaf sheaths during the first half of this experiment were similar in all treatments.

Although decreasing relative partitioning rates of nitrogen increase to leaf blades at the end of an experiment were also observed in Experiments 1 and 2, negative values (which indicate reallocation of nitrogen from leaf blades to other plant organs) were only found in Experiment 3. Nitrogen shortage as in N(0) of Experiments 3 and 4 stimulated the growth of the scape: the relative partitioning rates of dry matter and nitrogen increase to the scape at the end of an experiment (Figures 3C and F) were largest in N(0).

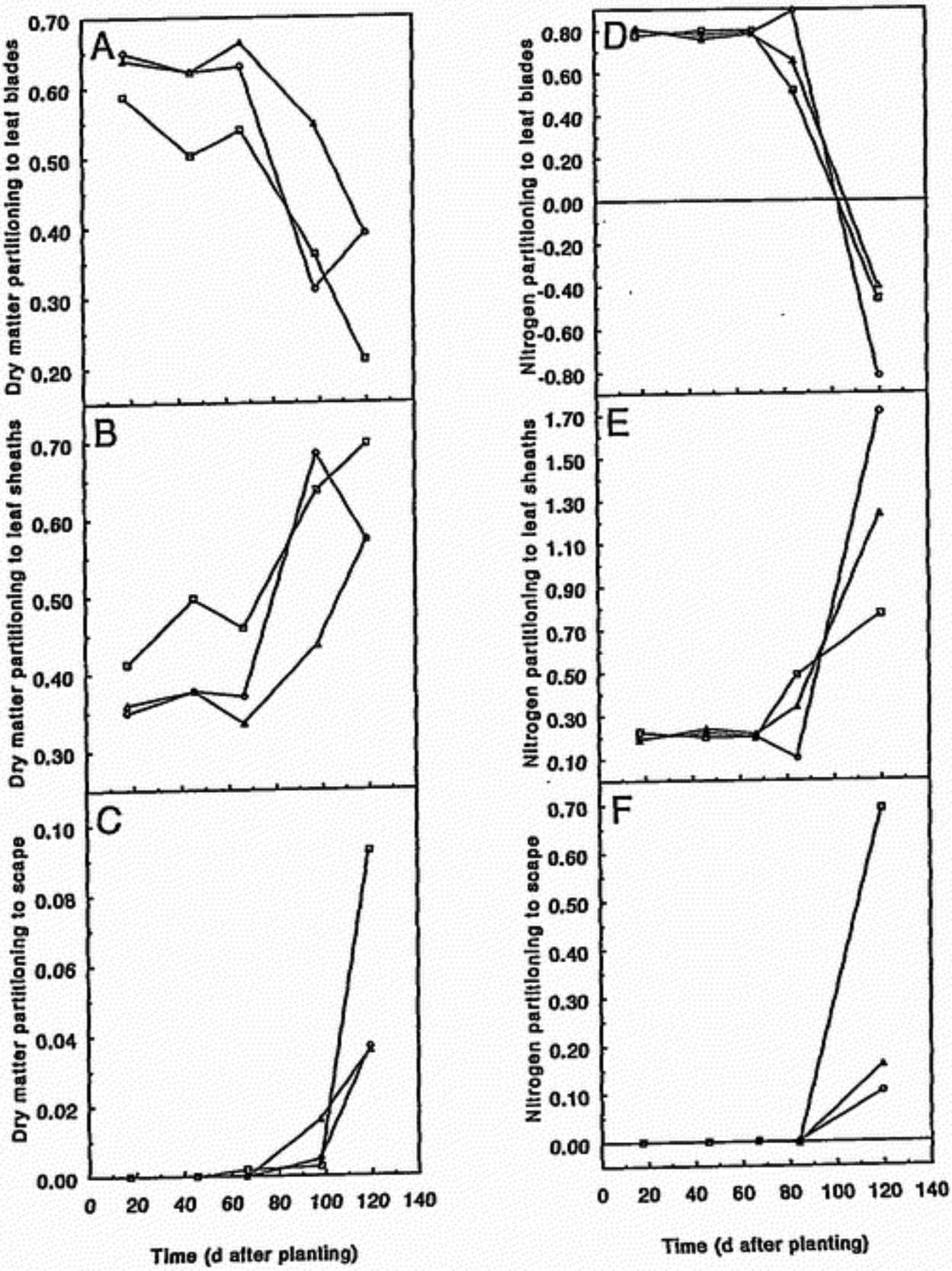

Figure 3. Changes with time in the relative partitioning rates of dry matter increase to the leaf blades (including dead ones; A), leaf sheaths (including dead ones; B) and scape (C) and changes with time in the relative partitioning rates of nitrogen increase to the leaf blades (including dead ones; D), leaf sheaths (including dead ones; E) and scape (F) of Experiment 3. Note differences in scales of y-axes. (□) N(0); (○) N(200/1); (△) N(200/5).

Table 1. The harvest index for dry matter and for nitrogen at 117 DAP for Experiment 1, at 167 DAP for Experiment 2, at 134 DAP for Experiment 3 and at 122 DAP for Experiment 4. Different superscript letters indicate that there was a significant difference between treatments. LSD values are included where factors had more than two levels.

Harvest index for dry matter

Experiment 1[1]		Experiment 2		Experiment 3		Experiment 4	
N(1.8/2)	0.488	N(1.0)	0.404[b]	N(0)	0.534[c]	N(0)	0.504[c]
N(1.8/6)	0.518	N(2.4;E)	0.415[b]	N(200/1)	0.461[b]	N(200/1)	0.406[b]
N(5.4/2)	0.459	N(2.4;L)	0.377[b]	N(200/5)	0.383[a]	N(200/5)	0.359[a]
N(5.4/6)	0.447	N(5.9)	0.318[a]				
		LSD	0.054	LSD	0.044	LSD	0.031

Harvest index for nitrogen

Experiment 1[1]		Experiment 2		Experiment 3		Experiment 4	
N(1.8/2)	0.266	N(1.0)	0.269[a]	N(0)	0.286[a]	N(0)	0.225[a]
N(1.8/6)	0.293	N(2.4;E)	0.269[a]	N(200/1)	0.352[a]	N(200/1)	0.233[a]
N(5.4/2)	0.285	N(2.4;L)	0.332[a]	N(200/5)	0.333[a]	N(200/5)	0.224[a]
N(5.4/6)	0.305	N(5.9)	0.269[a]				
		LSD	0.052	LSD	0.150	LSD	0.040

[1] applying 5.4 instead of 1.8 g N per pot and in two times instead of six had no significant effects.

Concentration of nitrogen and nitrate in plant organs of different nodes

Figure 4 shows the total nitrogen concentrations of different pairs of leaf blades and leaf sheaths in Experiment 4 at 60 and 122 DAP. The pattern for the leaf blades of Experiment 3 was similar to that for the leaf blades of Experiment 4 in Figure 4, but in Experiments 1 and 2 the total nitrogen concentrations of leaf blades at each harvest were higher at higher leaf numbers; this was caused by a decrease of the total nitrogen concentration of leaf blades with time. In Experiments 1 and 2 the concentrations of the lowest leaf blade numbers were about 2.5% and the concentrations of the highest leaf blade numbers decreased with time from 5.5 to 2.5%. Although in Experiments 3 and 4 the differences in the total nitrogen concentrations between different leaf blade numbers were negligible, the total nitrogen concentration of each leaf blade pair still decreased with time: all leaf blade pairs had lower concentrations at later harvests (see Figure 5).

The pattern of the total nitrogen concentrations of different leaf sheaths was similar in all experiments (Figures 4C and D: Experiment 4): this concentration increased with increasing leaf sheath number. The concentration in a certain leaf blade (pair) was always higher than in the corresponding leaf sheath (pair) (see Figure 5 for an example). The differences in nitrogen concentration between similar leaf blade and leaf sheath number were highest for the lowest observed leaf number and nearly negligible for the highest observed leaf number at a certain harvest.

Figure 5 shows an example of the changes in the total nitrogen concentration of

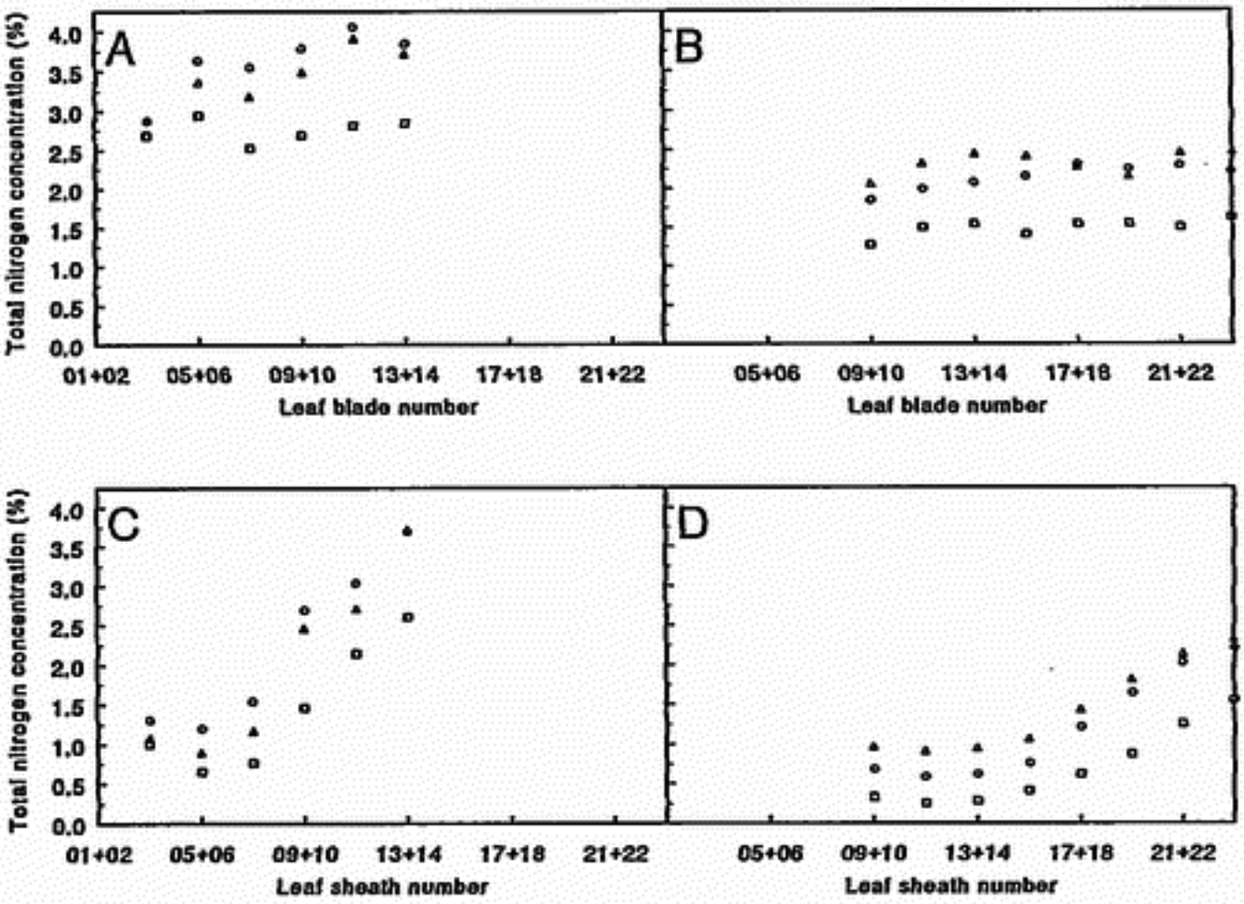

Figure 4. The concentration of total nitrogen in the dry matter of the different pairs of leaf blades (A and B) and leaf sheaths (C and D) for Experiment 4 at 60 (A and C) and 122 DAP (B and D). (□) N(0); (○) N(200/1); (△) N(200/5).

leaf blades and leaf sheaths with time. The differences in the rates of leaf appearance between the treatments were negligible (see Biemond, 1995); this leaf pair (9+10) appeared about 32 DAP. This implies that the starting value of the total nitrogen concentration was different between the treatments.

The nitrate nitrogen concentration of a leaf blade or leaf sheath (pair) was usually below 0.5% of the dry weight. At each harvest the highest concentrations were observed in the middle leaf numbers. The nitrate nitrogen concentration of a leaf sheath was between one and two times the nitrate nitrogen concentration of the corresponding leaf blade.

The average nitrate nitrogen concentrations over all above-ground plant parts were below 0.4% at all harvests of all experiments; usually they decreased with time. Final values were below 0.05%, except for the N(2.4;L) and N(5.9) of Experiment 2: they had average concentrations of 0.07 and 0.19%, respectively.

Discussion

Within experiments the accumulation of total dry matter and nitrogen of leek was affected in various ways by amount and timing of the nitrogen fertilisation. The differ-

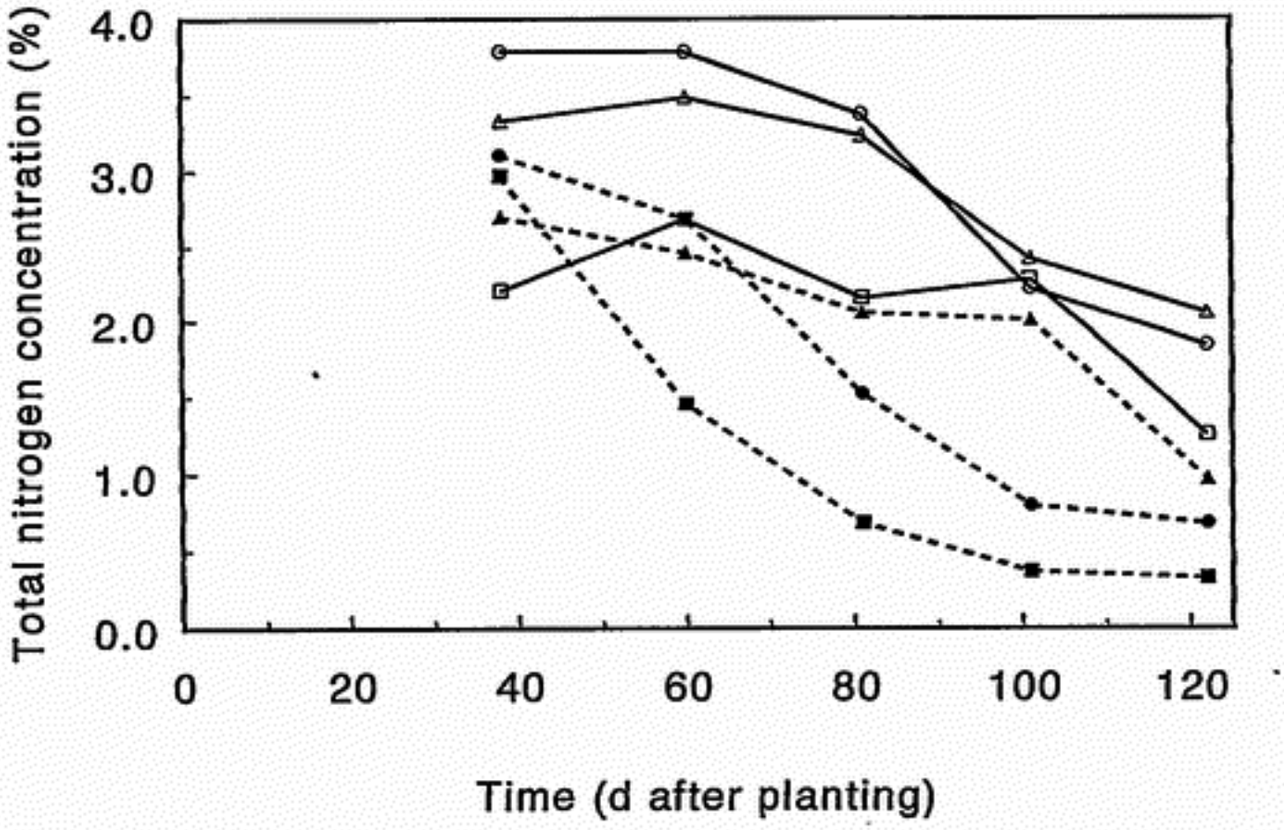

Figure 5. Changes with time in the concentration of total nitrogen in the dry matter of leaf blades 9+10 (open symbols; (□) N(0); (○) N(200/1); (△) N(200/5)) and leaf sheaths 9+10 (closed symbols; (■) N(0); (●) N(200/1); (▲) N(200/5)) of Experiment 4.

ences between the experiments are probably attributable to other factors, such as the amount of incident radiation. The maximum total dry matter production was in accordance with the value mentioned by Brewster (1994), viz. 1200 g m^{-2}; the maximum total nitrogen uptake (about 22.5 g m^{-2}) was about 10% below the uptake observed by Booij *et al.* (1993) in a comparable experiment.

Although the partitioning of dry matter in the current experiments was clearly affected by the nitrogen treatments, Booij *et al.* (1993) observed, with nitrogen fertiliser rates varying from 0 to 250 kg N ha^{-1}, a similar harvest index for dry matter of about 0.54 for all nitrogen treatments. The harvest index for nitrogen in the experiment of Booij *et al.* was equal to that for dry matter, while in this study much lower values were observed. A lower harvest index for dry matter at higher nitrogen rates, as observed in the current experiments, was observed by Greenwood *et al.* (1980) for crops as sugar beet, radish and swede, even when total dry matter was unaffected.

The final nitrate nitrogen concentrations observed are in accordance with the values, observed by Venter (1982) who found maximum values of about 0.05% of the dry weight.

The question arises why no increase in total nitrogen concentration with increasing leaf number was observed in leaf blades of Experiments 3 and 4. Such an increase is often found and explained by removal of nitrogen with leaf age. Allocation of nitrogen in the upper canopy layers is efficient for the plant since these leaves receive most of the light. (Hirose & Werger, 1987). However, assuming the light distri-

bution in the canopy affects the nitrogen distribution (see e.g. Hikosaka *et al.* (1994), who observed this for a vine), different parts of one leek leaf may have different nitrogen concentrations. This results from the leaf orientation, because the tip of a leaf (which is the oldest part) is exposed to higher light intensities than the base of a leaf, which is more overshadowed by higher leaves. These specific properties of leaves of leek may result in an alternation of the gradient in nitrogen concentration with leaf number.

The differences in the total nitrogen concentrations in leaf sheaths were probably the result of the differences in age between the leaves, the younger leaf sheaths having higher total nitrogen concentrations. However, the total nitrogen concentrations in the oldest two leaf sheath pairs were higher than expected according to the trends, probably because these leaf sheaths were exposed to the light and will therefore have contained some chlorophyll. This can also be the reason, why the highest nitrate nitrogen concentrations were not observed in the oldest leaf sheaths, but in the middle leaf sheath numbers: in the oldest leaf sheaths more nitrogen could be reduced, because the nitrate reductase activity was higher as result of the exposure to light. Darwinkel (1975) observed the highest nitrate concentrations in crops as turnip and rape in the oldest leaves: he explained this as a result of the low nitrate reductase activity in these leaves. In accordance with current results, Venter (1982) observed the highest nitrate concentrations in the middle leaf sheath numbers of leek.

The results from the current experiments show that a larger amount of available nitrogen does not necessarily lead to a higher dry matter yield of the shaft, because the harvest index for dry matter decreases. The harvest index for nitrogen was equal at different amounts of available nitrogen; this means the amounts of nitrogen in crop residues, which can leach below the rooting depth of the next crop, after mineralization, are higher at higher crop yields.

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