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Effect of NH_4-fertilization on the maintenance of a *Calluna vulgaris* vegetation

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SUMMARY

NH_4-fertilization in a natural, undamaged *Calluna* vegetation did not result in an immediate replacement of *Calluna vulgaris* by grasses. However, obvious changes were found in plant and soil composition that may lead to a greater stress sensitivity, but also to a lower regeneration capacity and a lower growth of *C. vulgaris*. Vegetative expansion of *Molinia caerulea* and *Deschampsia flexuosa* was higher in a *Calluna* vegetation damaged by a severe frost in the winter of 1986/1987 compared to growth in undamaged plots. The higher stress sensitivity of *C. vulgaris* due to nitrogen deposition may accelerate opening of the vegetation canopy. Once the vegetation has been opened, the negative effects of the high nitrogen input by the lower regeneration capacity and lower plant growth may speed up even more the transition of heathland into grassland.

Key-words: ammoniumsulphate, *Calluna vulgaris, Deschampsia flexuosa*, gap-formation, *Molinia caerulea.*

INTRODUCTION

Heathlands dominated by *Calluna vulgaris* were a common feature in large parts of The Netherlands. This semi-natural vegetation type was characterized by a low soil fertility, intensified owing to the common practice of sheep grazing and sod cutting. Nutrients were transported from heathland to agricultural land, maintaining the nutrient poor state of the soil. In this ancient agricultural system, the balance between input and output of nutrients was more or less kept in equilibrium for the long term (De Smidt 1977; Gimingham & De Smidt 1983). However, this balance has been disturbed by the introduction of mineral fertilizers. Most heathland area was transformed into arable land or forest, and the remaining heathland declined because of the changed management and the resulting increasing nutrient levels.

Since 1970, an accelerated change from heathland to grassland has been observed. *C. vulgaris* is rapidly being replaced by *Molinia caerulea* and *Deschampsia flexuosa.* Although temporal dominance of grasses is a normal phase in rejuvenation of a *Calluna* vegetation (Watt 1955; Gimingham 1972), today's grasslands have a more permanent character.

The key factor initiating the transition from heathland to grassland is injury by additional stress factors e.g. drought, frost, heather beetle damage (Berdowski 1987;

Berdowski & Zeilinga 1987). Damage to *C. vulgaris* caused by these stress factors may provide gaps in the canopy and therefore sufficient light for the grass species to grow and to compete for space. In a *Calluna* vegetation where stress factors have occurred, fast growing species like *M. caerulea* and *D. flexuosa* may have an advantage over the slower growing *C. vulgaris* (Grime & Hunt 1975).

Deposition of nitrogen was estimated at only about 5 kg N ha^{-1} y^{-1} at the beginning of this century, raising to *circa* 10 kg N ha^{-1} y^{-1} in 1950 and to an input as high as 35–40 kg N ha^{-1} y^{-1} in 1990 (J.W. Erisman, personal communication). The loss of heathland and the increasing dominance of grasses have been ascribed to the increasing air pollution. The competitive strength of the grass species *M. caerulea* and *D. flexuosa* may even be enhanced at a higher nitrogen availability.

For the Violion caninae species, a correlation between SO_2-concentration and the decline of these species has been shown (Van Dam *et al.* 1986). Some studies showed a decline of the *Calluna*-dominated heathland area caused by the higher nitrogen input owing to an increasing air pollution (Diemont & Heil 1984; Brunsting & Heil 1985; Heil & Bruggink 1987). On the other hand however, undamaged *Calluna* vegetation was found to have a higher competitive ability than *M. caerulea* even at a nitrogen deposition of 200 kg ha^{-1} y^{-1} (Aerts 1989a). Therefore, we first of all determined which changes occur in plant and soil content during a 2-year period due to an increased nitrogen input. We hypothesize (1) that an increasing level of nitrogen deposition results in an increased turnover of *C. vulgaris*: a higher litter production and an increasing biomass of dead plant material. We also hypothesize (2) that an increasing level of nitrogen deposition results in an increased nitrogen content of the leaves and a change in soil solution contents.

The next aim of our study was to quantify the effect of gap formation in combination with an increasing nitrogen input, on establishment and growth of the grass species *M. caerulea* and *D. flexuosa*. We hypothesize (3) that gap formation stimulates vegetative expansion of *M. caerulea* and *D. flexuosa* compared to growth of these species in a closed *Calluna* vegetation. Finally, we hypothesize (4) that this stimulating effect is more pronounced in plots with a higher nitrogen input.

MATERIALS AND METHODS

The study was carried out from July 1987 to October 1989 in the heathland nature reserve 'Asselse Heide' (52°12′N, 5°51′E) near Apeldoorn, The Netherlands. The vegetation in this study site can be ascribed to the Genisto-Callunetum. The soil can be characterized as nutrient-poor fluvio-glacial sand with a well-developed podzolic soil profile.

C. vulgaris was 8–12 years old at the start of the experiment. Canopy height was approximately 40–50 cm. In the winter of 1986/1987 vegetation in part of the area was severely damaged by frost, causing gaps in the formerly closed vegetation. Plots (36; 3 × 3·5 m) were chosen in the undamaged *Calluna* vegetation (no visible frost damage) and 24 plots were situated in the damaged *Calluna* vegetation (*circa* 50% of the plants damaged by frost).

Nitrogen was given as solutions of ammoniumsulphate, at concentrations that corresponded to 0, 10, 50, and 90 kg N ha^{-1} y^{-1}. These nitrogen gifts are extra gifts in addition to the yearly natural input of *circa* 35–40 kg N ha^{-1} y^{-1}. Plots were watered 10 times a year, using a solution of 15 l water containing those four different $(NH_4)_2SO_4$ concentrations. The 2 months when the plots were not watered with this nutrient solution were December

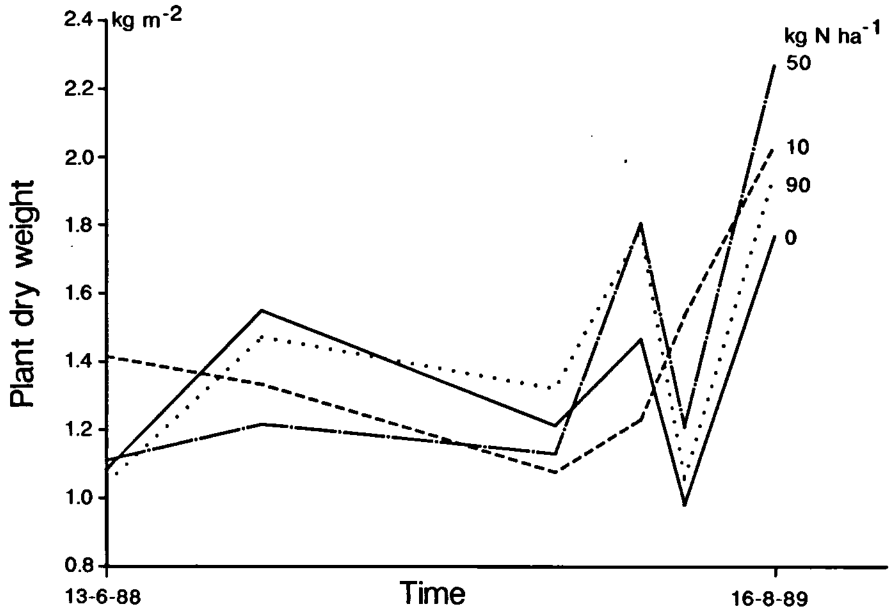

Fig. 1. Plant dry weight (living and dead plant material) of *Calluna vulgaris* in undamaged vegetation at various levels of nitrogen input ('Asselse heide', near Apeldoorn, The Netherlands).

and January. At this time of the year, it is likely that a frost will occur, so that the water solution would not be able to enter the soil.

The results were tested statistically (Genstat 5·0) using an analysis of variance test. Statistically significant differences are mentioned in the results as 'significant differences'.

The effect of $(NH_4)_2SO_4$ in an undamaged Calluna *vegetation*

In July 1987, 12 plots in the undamaged *Calluna* vegetation were chosen to study the effect of the four different nitrogen treatments (three replicates per treatment).

(a) Plant growth was determined by harvesting subplots (30 x 30 cm) per plot six times from 13-6-1988 to 9-10-1989. Plant parts were dried at 70°C for 48 h and weighed.

(b) On eight dates from 13-6-1988 to 9-10-1989 *C. vulgaris* was harvested in subplots (30 x 30 cm) in each plot and nitrogen, phosphate and potassium concentrations of the aboveground plant parts (green parts, flowers and wood) were determined. Also, N-concentration of *C. vulgaris* roots was determined six times from 13-6-1988 to 19-10-1989. Total N was determined chromatographically on a Carlo Erba Strumenzione after burning the plant parts at 1000°C. K-content was determined by microwave digestion and analysis on an Atomic Absorption Spectrometer. P-content was determined colorimetrically on an Auto-analyser.

(c) To compare litter production in the four different nitrogen treatments, three funnels (diameter 15 cm) were placed in each plot to collect litter. Litter production was determined in 16 periods from 25-8-1988 to 17-10-1989.

(d) The pH and composition of the soil solution was examined seven times during the experiment, from December 1988 to October 1989. Ceramic cups were buried in the soil at a depth of 5 cm and 15 cm. The soil solution was collected in these ceramic cups. We determined NO_3, NH_4, K, Ca, Mg, and Al-concentration by microwave digestion on an Atomic Absorption Spectrometer.

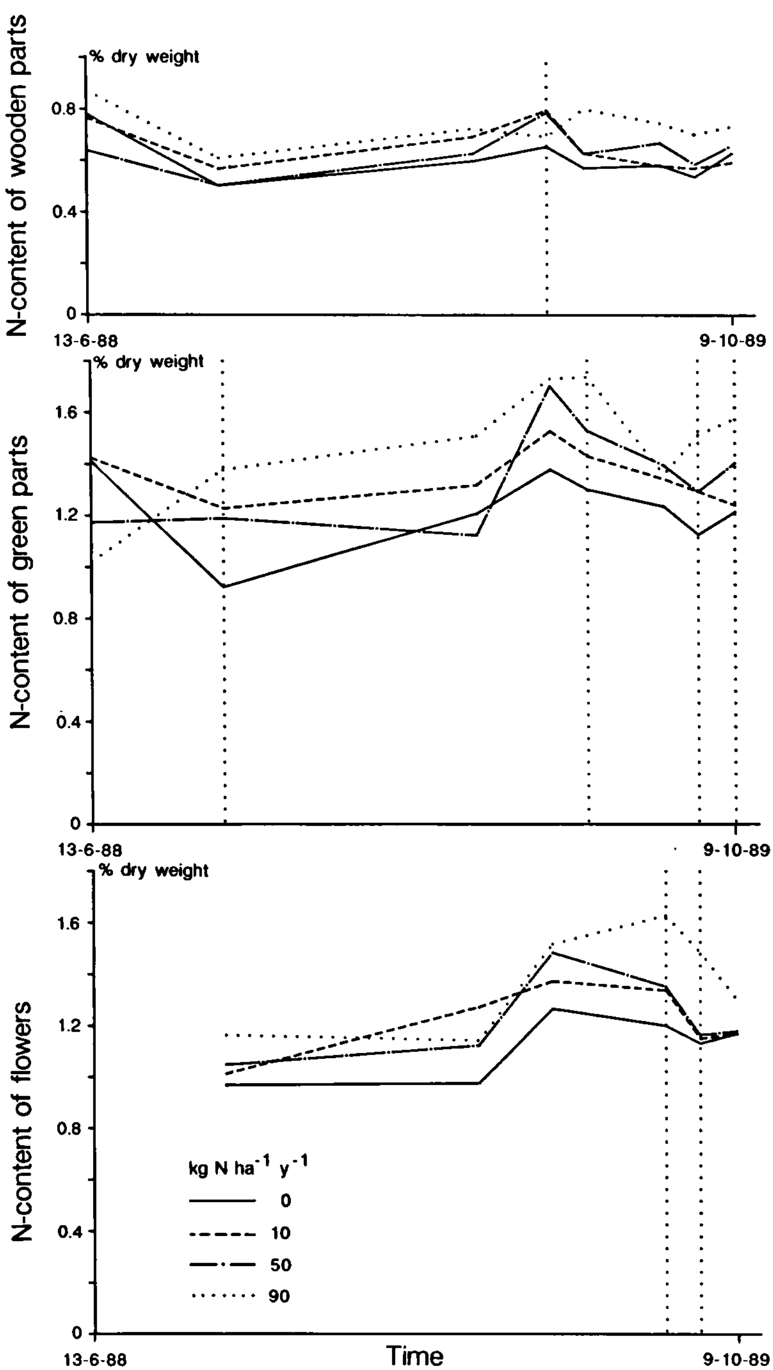

Fig. 2. Nitrogen content of *Calluna vulgaris* plant parts during the experiment. (a) wooden parts, (b) green parts, (c) flowers. Significant differences between the nitrogen treatments at a harvest day are indicated by a vertical dotted line.

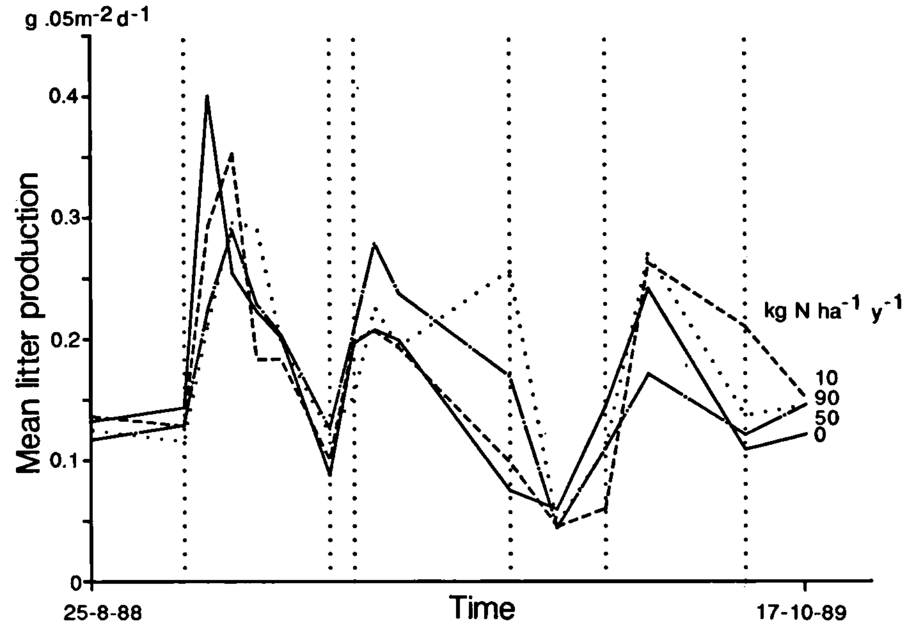

Fig. 3. Litter production of *Calluna vulgaris* during the experiment. Significant differences between the nitrogen treatments at a harvest day are indicated by a vertical dotted line.

(e) In October 1990, the total phosphate concentration of the top 5 cm of the mineral soil was determined. We took three subsamples per plot, and combined the subsamples of each of the four different nitrogen treatments. Phosphate was determined by microwave digestion and analysed colourimetrically on an Auto-analyser.

The effect of frost damage on vegetative expansion of M. caerulea *and* D. flexuosa

The experiments were performed in 24 plots in both the damaged and the undamaged *Calluna* vegetation. In July 1987, *M. caerulea* was planted in half of the plots, in the other half we planted *D. flexuosa.* The grasses used were 1–2 years old. In each plot 56 tillers were planted at a distance of 50 cm apart. We thus had 12 plots per 'vegetation type' (damaged and undamaged) with either *M. caerulea* or *D. flexuosa.* These 12 plots were subdivided in four groups with a different nitrogen treatment (0, 10, 50, 90 kg N ha^{-1} y^{-1}). In October 1989, 2 years after the experiment had started, grasses were harvested in the central part (2·5 × 2·0 m) of all plots. Number of tillers and plant dry weight were determined.

RESULTS

The effect of $(NH_4)_2SO_4$ in an undamaged Calluna *vegetation*

(a) No significant differences were found in total plant dry weight (living and dead plant material) (Fig. 1), and also in dry weight of the green parts of the plants, root dry weight and biomass of the dead plant material.

(b) At the end of the experiment, in both green parts of the plant and flowers, nitrogen content was significantly higher in the highest N-treatment (Fig. 2b and c). For the wooden parts of the plant, the same trend was found, but it was not significant (Fig. 2a).

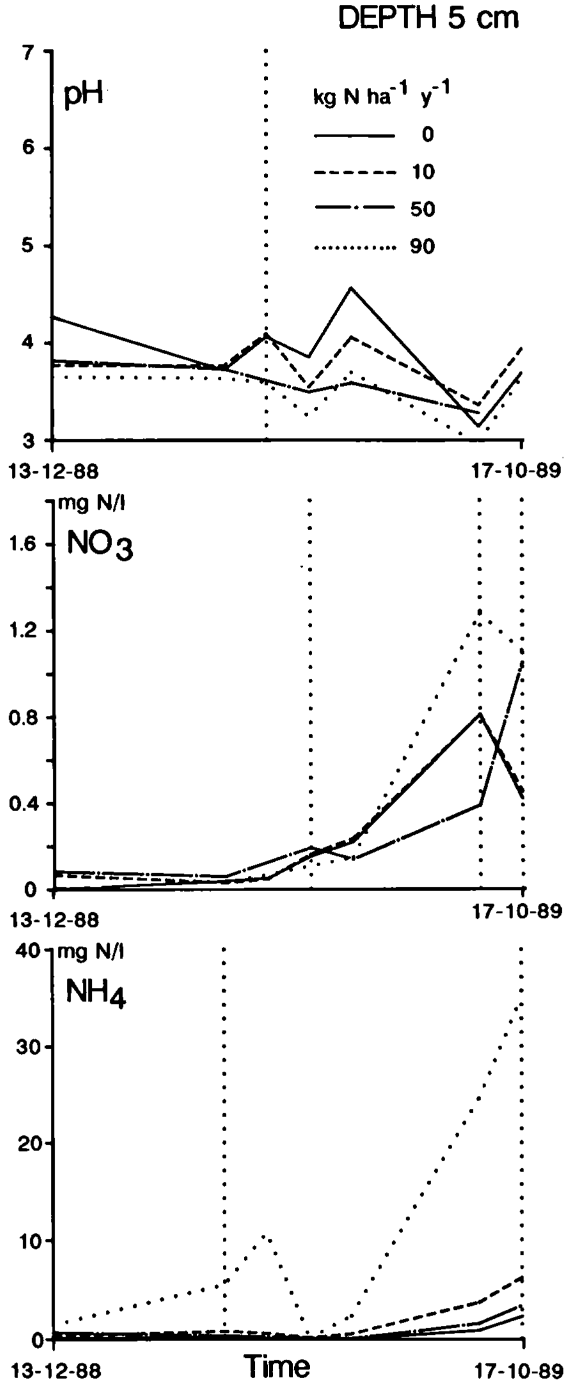

Fig. 4. Composition of the soil solution in the *Calluna vulgaris* plots at 5 cm depth, from December 1988 until October 1989. a = pH, b = NO_3, c = NH_4. Significant differences between the nitrogen treatments at a harvest day are indicated by a vertical dotted line.

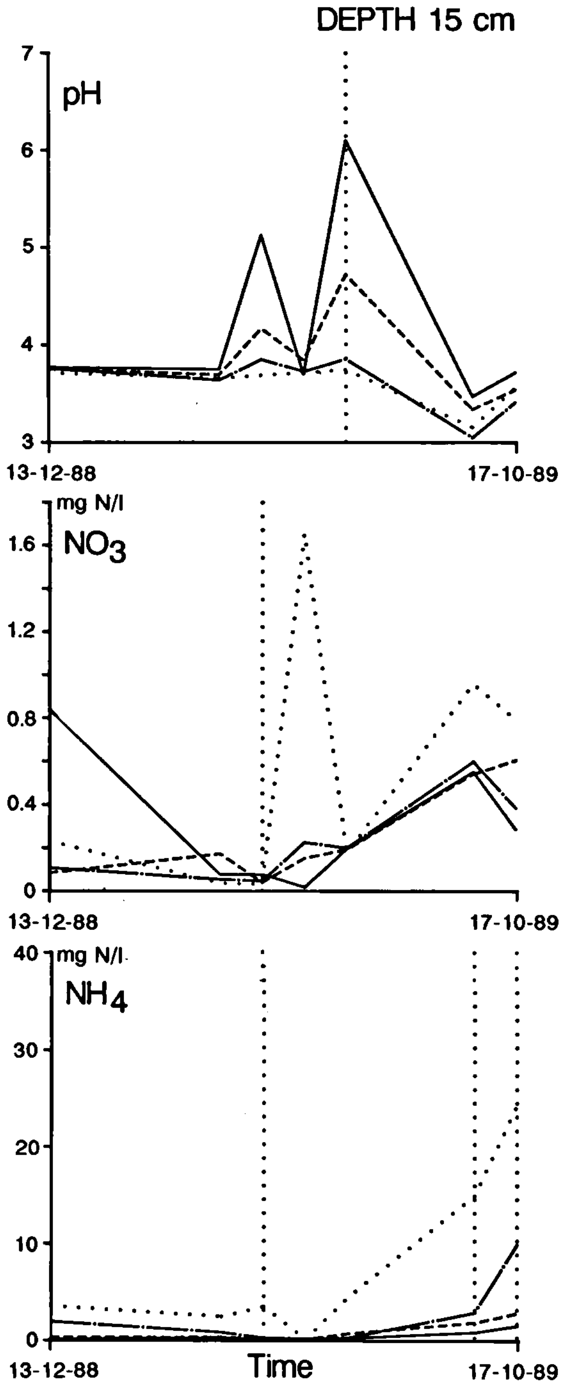

Fig. 5. Composition of the soil solution in the *Calluna vulgaris* plots at 15 cm depth, from December 1988 until October 1989. a = pH, b = NO_3, c = NH_4. Significant differences between the nitrogen treatments at a harvest day are indicated by a vertical dotted line.

No significant differences were found in phosphate concentrations in the green plant parts, the flowers or the wooden plant parts until the last harvest (16-8-1989). At that time, we found a relatively high phosphate concentration in each of the three mentioned plant parts at the lowest N-treatment. Potassium concentrations did not show significant differences between the four N-treatments. The P/N ratio of the green parts of *C. vulgaris* was very low and varied from 0·032 to 0·058. For the nitrogen content of *C. vulgaris* roots, we did not find significant differences during the experiment.

(c) Large temporal fluctuations were found in litter production of *C. vulgaris* during the experiment, but no treatment effects were found (Fig. 3).

(d) At the lowest level of fertilization, soil solution pH was largely highest (Figs 4a and 5a). NO_3-concentration increased sharply during the experiment at 5 cm depth. This increase is less clear at 15 cm depth. A significantly higher NO_3-concentration at 5 cm depth was found for the highest N-treatment at the end of the experiment (Fig. 4b). NH_4-concentration also increased during the experiment, except for the control treatment (0 kg N ha^{-1} y^{-1}). Increase is largest at the highest N-treatments (Figs 4c, 5c). Cation concentrations (K, Ca, Mg, Al) showed an increase during the experiment, although least clear for the blanco treatment. At 5 cm depth the increase was more gradual. For all cations, a trend was found towards higher concentrations at higher N-treatments.

(e) The total P-concentration of the top 5 cm of the mineral soil was very low and varied between 60 and 101 ppm under all conditions.

The effect of gap formation on growth and establishment of M. caerulea *and* D. flexuosa

In the damaged vegetation, number of tillers and plant dry weight were higher than in the undamaged vegetation (Fig. 6). For *M. caerulea*, this effect is significant for the highest N-gifts (50 and 90 kg N ha^{-1} y^{-1}). For *D. flexuosa*, number of tillers is significantly higher in the damaged *Calluna* vegetation for all N-treatments. In the undamaged vegetation, we did not find any effect of an increased nitrogen gift (Fig. 6).

DISCUSSION

In undamaged *Calluna* vegetation an increase in the N-input caused a change in plant and soil composition. As in earlier experiments (Loach 1966; Wong 1975), we found a higher nitrogen content in the green parts of the plant and in the flowers due to a higher N-deposition. We did not find any differences in plant biomass of *C. vulgaris* in the four nitrogen treatments. We suppose that while nitrogen may possibly be deficient in the low N-treatment, phosphate is probably deficient in the higher N-treatments. An indication for a phosphate-deficiency is given by the very low total P-content of the above 5 cm of the mineral soil in our study area (60–101 p.p.m.), much lower than the 400 p.p.m. total phosphate that was found to be critical for plant growth in England (Loach 1966). Moreover, at a N-concentration of the leaves between 1 and 2% of the dry weight of the plant, the very low P/N-ratio of the green parts of *C. vulgaris* (0·032–0·058) also points to a phosphate deficiency. This deficiency may be induced by growth stimulation at high nitrogen treatments. In an experiment in old wet heathlands both *M. caerulea* and *Erica tetralix* responded strongly to P-fertilization (Aerts 1989a). These wet heathlands are also supposed to be P-limited and not N-limited, due to the high atmospheric N-deposition. In contrast to our first hypothesis, we did not find an effect of the increasing nitrogen gift on litter production and dead plant material. Aerts (1989b) also did not find any differences in leaf turnover in *C. vulgaris* at an increasing nutrient availability.

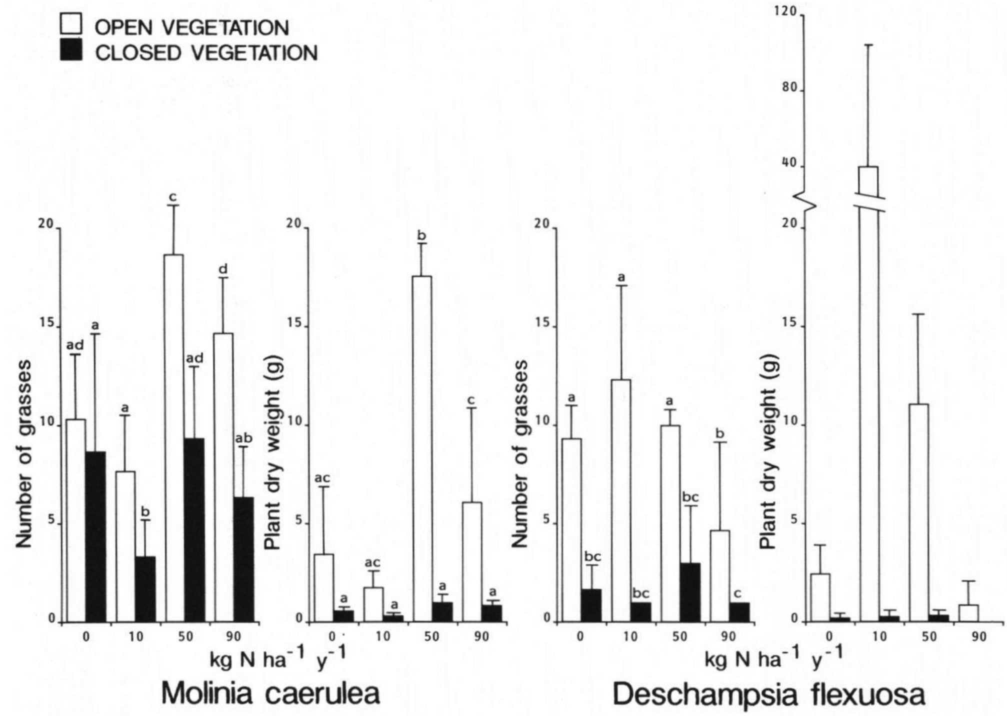

Fig. 6. The effect of gap formation and fertilization with NH_4 on the number of tillers and plant dry weight in *Molinia caerulea* and *Deschampsia flexuosa* planted 2 years before. Different characters indicate significant differences between the treatments.

The higher nitrogen content in the green parts of the plant and in the flowers as a result of increasing N-gift will lead to an increased N-content in the litter. Moreover, obvious changes were found in the soil composition due to the different N-treatments. These changes in the vegetation and in the soil apparently do not have a direct effect on transition of heathland into grassland. This conclusion is confirmed by our experiments in the undamaged *Calluna* vegetation, in which grasses were planted. No effect on growth was found of either *M. caerulea* nor *D. flexuosa* as a result of the N-treatments.

As an indirect effect of the changes of plant and soil solution by a higher N-input, however, an increase in stress-sensitivity of *C. vulgaris* may be important. Leaf damage of potted *C. vulgaris* due to a severe summer drought in 1989 was much higher in plants with a high NH_4-gift (Berdowski, unpublished results). The increased nutrient content of the *Calluna* leaves and therefore the better food quality, may lead to an increased sensitivity of the plant to the attack of the heather beetle (*Lochmaea suturalis*) (Brunsting & Heil 1985; Heil & Bruggink 1987). Moreover, regeneration of *C. vulgaris* may decrease as a result of the increased nutrient levels (Berdowski 1987). Finally, in the present study we found a decrease in soil pH below 3·5 at the highest N-gifts. This decreasing pH reduces relative growth rate of *C. vulgaris*. Optimal growth was found for *C. vulgaris* at pH = 4·5 (Niers & Van der Boon 1986). In contrast, the grass species *M. caerulea* and *D. flexuosa* are only negatively affected at a pH lower than 3·0 (Berdowski, unpublished results). Acidification of the soil may lead to leaching of cations (Van Breemen *et al.* 1984), that was actually found in our study: with increasing nitrogen concentration in the added solution there were higher cation contents in the soil. Leaching of cations has shown to be an important parameter causing the extinction of *Arnica montana*, a characteristic heathland species (Fennema, subm.).

The combined effect of the increased stress sensitivity, decreased regeneration capacity and a decreasing plant growth of *C. vulgaris* at a lower pH due to a higher nitrogen input may lead to a change in competition between *C. vulgaris* and *M. caerulea* and *D. flexuosa*. However, as long as the vegetation canopy is closed and no additional stress factor occurs, *C. vulgaris* will not be substituted by grasses, even at a nitrogen deposition of 200 k N ha^{-1} y^{-1} (Aerts 1989a).

In accordance with our third hypothesis, we did find an increase in grasses in the *Calluna* plots that had been opened by the severe frost in the winter of 1986/1987 compared to the undamaged plots. The positive effect on plant growth caused by the opening of the vegetation was intensified by the higher nitrogen input (hypothesis 4).

Therefore, we conclude that although a high nitrogen deposition in the closed *Calluna* vegetation did not directly lead to a replacement of *C. vulgaris* by grasses, the changing plant and soil composition will lead to a greater stress sensitivity of *C. vulgaris*, and accelerate the substitution of *C. vulgaris* by grasses once the vegetation has been opened.

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