NITROGEN BALANCES DURING GROWTH OF BRUSSELS SPROUTS AND LEEKS

R. Booij, P. De Willigen, A.D.H. Kreuzer, A.L. Smit and A. Van der Werf
Research Institute for Agrobiology and Soil Fertility (AB-DLO)
P.O. Box 14
NL-6700 AA Wageningen
The Netherlands

Keywords: *Allium porrum* L., *Brassica oleracea* L. var. *gemmifera*, KNS, leaching, model, nitrogen balance, nitrogen losses, Nmin

Abstract

The nitrogen balance at different N-application rates was determined in Brussels sprouts and leeks during growth of the crop in two field experiments on a sandy soil. The N-input (from fertilizer and mineralisation) and the N-output (N in the above-ground crop parts and the residual mineral N in the soil (Nmin)) were calculated. No deficit on the nitrogen balance was observed during crop growth of Brussels sprouts up to a fertilizer rate of 300 kg ha^{-1}. In leeks no deficit was found when 125 kg ha^{-1} N was applied, but a deficit in the balance developed from 90 days after transplanting, when 250 kg ha^{-1} N was applied at the time of transplanting. In one year this deficit in leeks was 160 kg ha^{-1} N at the beginning of September. Based on a simulation study of the nitrate movement in the soil, it was concluded that the deficit in the balance in leeks was in fairly good agreement with the amount of nitrogen leached from the soil layer (0-60 cm) at the final harvest (November).

At the final harvest the level of mineral nitrogen in the soil (0-60 cm) was less than 20 kg ha^{-1} N at all N-application rates in both crops. The uptake of nitrogen during the last part of the growing period of leeks played an important role in maintaining the green colour intensity.

The results are discussed in view of the need for a mineral nitrogen buffer as prescribed in nitrogen management systems, based on KNS (Lorenz et al., 1989).

1. Introduction

Nitrogen fertilizer is an important growth factor for controlling yield and quality of field vegetables. The cost of fertilizer input is low compared with the financial output of the marketable product, making high application rates commercially acceptable (Neeteson and Wadman, 1987). But when nitrogen is applied at recommended rates, the recovery of applied nitrogen by a number of crops is low (Smit and Van der Werf, 1992). This means that mineral nitrogen remains unused in the field, which may threaten the environment (Greenwood, 1990). As the nitrogen uptake required to reach optimal yield cannot be predicted at the start of crop growth due to variable weather conditions, extra nitrogen is often applied to avoid the risk of yield reductions, with the result that the amount of residual nitrogen remaining after harvest is often large (Greenwood, 1990). A significant reduction of these nitrogen residues was achieved when the mineral nitrogen available in the soil at the onset of crop growth was included in the recommendations (Wehrman and Scharpf, 1989; Hähndel and Isermann, 1993).

Most recent research has focused on the residual nitrogen after harvest, which is susceptible to leaching during the period between crops. Far less attention has been paid to losses during crop growth. An estimate of these losses of mineral nitrogen can be obtained by calculating the balance for mineral nitrogen by comparing nitrogen input and output (Hansen, 1989). Nitrogen input is the sum of the mineral nitrogen from fertilizer, mineralisation of organic matter (accumulated before and during crop growth) and deposition. If the nitrogen in the above-ground crop parts and the residual mineral nitrogen in the rooted zone is considered as the nitrogen output, the difference between the nitrogen input and the nitrogen output is the deficit in the nitrogen balance and indicates losses of mineral nitrogen (temporarily or permanent). Nitrogen losses can occur due to immobilisation, leaching, erosion, denitrification or chemical fixation (Huggins and Pan, 1993). Only leaching and denitrification can be assigned as direct losses to the environment, which may be hazardous.

When calculating the nitrogen balance at a number of times during crop growth, the time course of the deficit can be studied and possible losses identified. The information obtained from this analysis can be used to develop strategies to prevent the losses during the growing season. However, if no deficit develops during crop growth losses can still occur after harvest when residual mineral nitrogen and nitrogen from decomposed crop residues may disappear (Wehrmann and Scharpf, 1989).

The aim of the present paper is to calculate the nitrogen balance, as earlier stated, during growth of Brussels spouts and leeks at different nitrogen application rates, *1)* to identify the time course of losses of mineral nitrogen and *2)* to identify differences between crops. By using a simulation model that describes the nitrate movement in the soil, leaching of nitrate during crop growth was estimated and compared with the deficit in the balance. Brussels sprouts and leeks were selected, because of a large difference in their nitrogen utilisation (Smit and Van der Werf, 1992).

2. Material and methods

2.1 Experiments

Field experiments were carried out with Brussels sprouts and leeks in 1991 and 1992 on a sandy soil. In the 1991 experiment nitrogen fertilizer rates in Brussels sprouts were 0, 100, 200 or 300 kg ha^{-1} N and in leeks 0, 125 or 250 kg ha^{-1}, applied before transplanting. In 1992 0, 50, 100 or 200 kg ha^{-1} N was applied in Brussels sprouts and 0 or 250 kg ha^{-1} N in leeks. For leeks grown in 1992, there was an additional set of fertilizer treatments, being no fertilizer at transplanting but 60 or 90 kg ha^{-1} N at the beginning of September, or 125 kg ha^{-1} N at transplanting + 125 kg ha^{-1} N at the beginning of September. Crops were transplanted at the end of May or at the beginning of June. Above-ground biomass and mineral nitrogen (nitrate + ammonium (Nmin)) were assessed at regular intervals for each fertilizer application rate, until the final harvest in November. Details of the experiments are given by Booij et al. (1996).

Dry matter content was determined after drying 24 hours at 105 °C. Total N concentration (nitrate + organic N) in the dry matter was determined using the Dumas-method. Nitrogen uptake was calculated as the product of total dry matter yield and the nitrogen concentration. At each harvest date cumulative nitrogen uptake included the nitrogen content of the dropped leaves.

Soil samples were taken on 6 spots within each plot of Brussels sprouts and on 3 spots within each leek plot from the soil layer 0-60 cm. Nitrate and ammonium (Nmin) were extracted with 1N KCl and determined colorimetrically. Green leaf blade intensity was measured on 10 plants with a hand-held chlorophyllmeter (SPAD-502 chlorophyll meter, Minolta Camera Co., Ltd, Japan) (Wood et al., 1992).

The nitrogen balance for mineral nitrogen was defined as:

$N_{input} = N_{output}$

where,

$N_{input} = N_f + N_m + N_d$

(N_f = N from fertiliser, N_m = N from mineralisation and N_d = N from deposition)

and

$N_{output} = N_c + N_r$

(N_c = N contained in above ground crop parts and N_r = the residual mineral nitrogen in the soil (0-60 cm)).

(N_m+N_d) was estimated from the (N_c+N_r) in the unfertilized plot, assuming no losses from the unfertilized plots.

If $N_{input} > N_{output}$ a deficit in the nitrogen balance occurred.

2.2 Description of the model

The model used consisted of four modules: water transport, water uptake, nutrient transport and nutrient uptake. It has been described in detail by De Willigen et al. (1995), but a brief summary is given below.

2.2.1 Water transport

The model uses FUSSIM2 (Flow of water in Unsaturated (vadose) Soil Simulation Model in two dimensions (Heinen and De Willigen, 1992)). This module contains details of the governing flow equation, boundary conditions, the numerical (finite difference) discretization steps for the flow equation and the boundary conditions, possible ways to obtain average hydraulic conductivities, and the solution procedure.

2.2.2 Water uptake

Water uptake is calculated by a microscopic numerical uptake model, described by De Willigen and Van Noordwijk (1994). This describes the flow of water to a root in terms of two components: one describing the flux of water from the bulk soil to the root surface by Darcy's equation and the second describing the inward flux over the root surface as the product of the root conductivity and the difference in pressure head between the soil at the root surface and in the root.

2.2.3 Nutrient transport

Transport of solutes is by mass flow and diffusion/dispersion. The transport is calculated by multiplying the flux of water over a face of two adjacent compartments by the concentration in that compartment for which the direction of the flux is outward.

2.2.4 Nutrient uptake

As long as the concentration at the root surface remains greater than zero, nitrogen upake is determined by the plant demand. When the concentration at the root surface becomes zero, the uptake rate is determined by the maximum rate at which the nitrogen is transported towards the root surface (Willigen and Van Noordwijk, 1989).

2.2.5 Input values

Root distribution: Root length density distributions were measured at different times, and used as input, with values between sampling dates determined by interpolation.
Soil hydraulic properties: Data for the moisture retention curve of the top- and subsoil were fitted to Mualem-Van Genuchten equation.
Nitrogen uptake and demand: The nitrogen demand was defined as the measured nitrogen uptake and was used as input in the model. The nitrogen supply by mineralization was estimated at 0.5 kg ha^{-1} d^{-1}, at a temperature of 14 °C; the model automatically calculated the rate of mineralization as a function of temperature, with a Q_{10} of 2.
Water uptake and transpiration: The root conductivity was set at 5.10^{-6} $cm.d^{-1}$. Reduction of transpiration was assumed to begin when plant water potential falls below -0.5 MPa.

3. <u>Results</u>

N-uptake increased during growth for both crops and the total N in the crop at the final harvest increased with increasing N-application rate (Figure 1). The rate of N-uptake was higher and the effect of N-application on N-uptake was greater in Brussels sprouts than in leeks. Mineral N-supply in the soil (Nmin) decreased during crop growth and the rate of decrease was higher by Brussels sprouts (Figure 1). At all N-rates mineral soil nitrogen was depleted in Brussels sprouts within about 77 days. Despite the depletion of mineral N in the soil, N-uptake continued for some time (Figure 1). In both crops the mineral soil N was depleted at the final harvest.

The N-input was compared with the N-output to identify losses of plant available nitrogen during crop growth. In Brussels sprouts N-output approached N-input at all harvest dates and N- application rates (Figure 2), with the exception that N-input at the highest fertilizer rates was slightly higher than the N-output during early crop growth.

This equilibrium in the balance between input and output was observed in both experimental years. In leeks N-input almost equalled N-output throughout the whole crop growth when 125 kg ha^{-1} N was applied (Figure 3). When 250 kg ha^{-1} was applied, however, N-output was consequently lower than the N-input, resulting in deficit of 98 kg ha^{-1} N by the final harvest. In 1992 there was a large difference between N-input and output at 95 DAP, at the N-application rate of 250 kg ha^{-1} leading to a final deficit of 160 kg ha^{-1}N (Figure 3). In both years N-output in leeks reached a minimum at about 90 DAP, followed by an increase of 30-50 kg ha^{-1} during the next 40 days (Figure 3), when 250 kg ha^{-1} N was applied. A main difference between these two years was the contribution of mineralisation, this component was higher in 1992 (Figure 1).

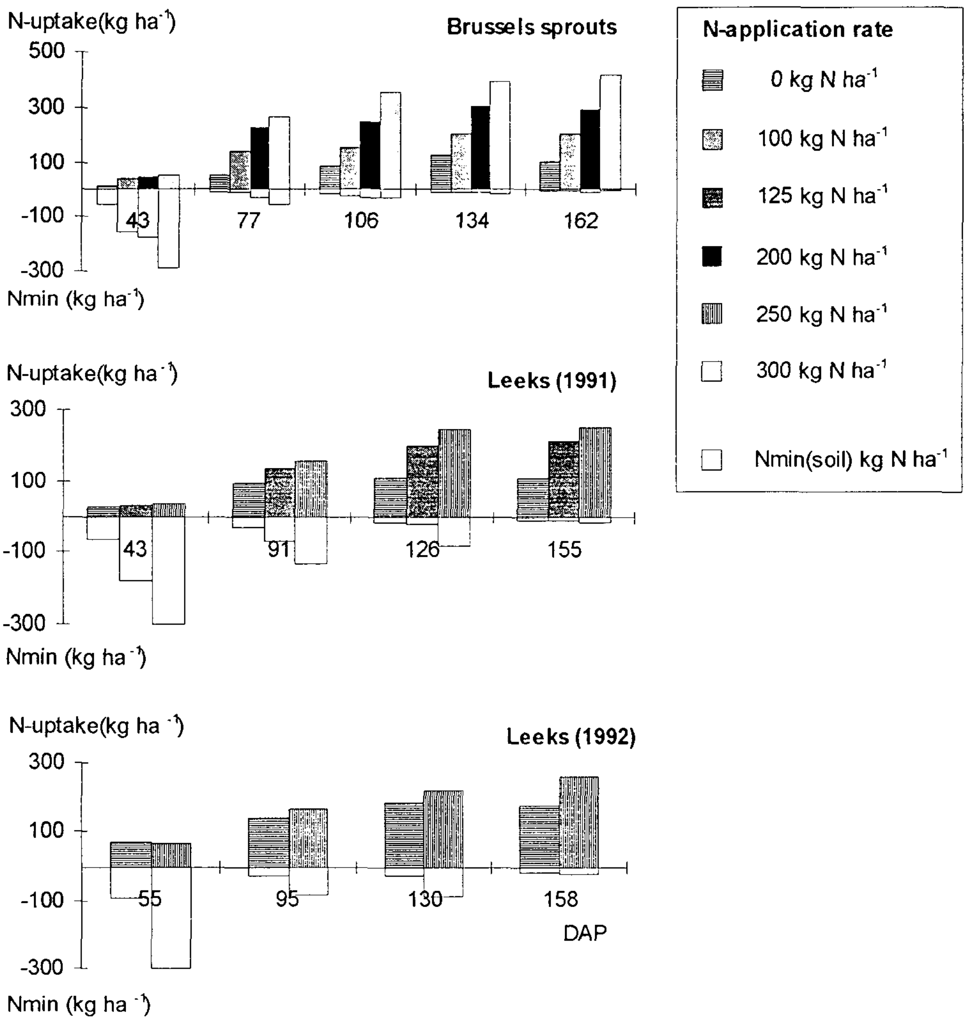

Figure 1: Crop nitrogen content (kg ha^{-1}N) and the soil mineral nitrogen content (Nmin, kg ha^{-1} N) in the soil layer 0-60 cm of Brussels sprouts (1991) and leeks (1991and 1992) at different times (days) after transplanting (DAP).

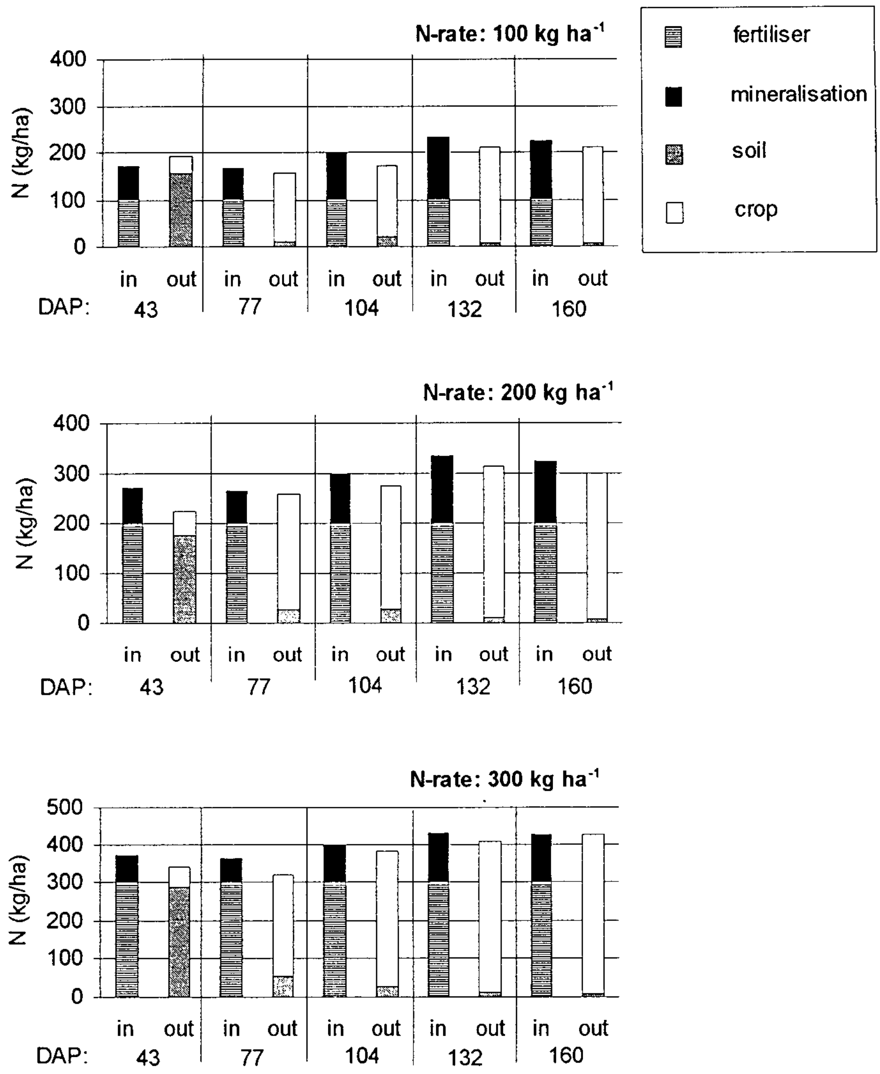

Figure 2: The nitrogen input (mineralisation, fertilizer) and output (residual Nmin, crop uptake) of Brussels sprouts at different N-rates in 1991.

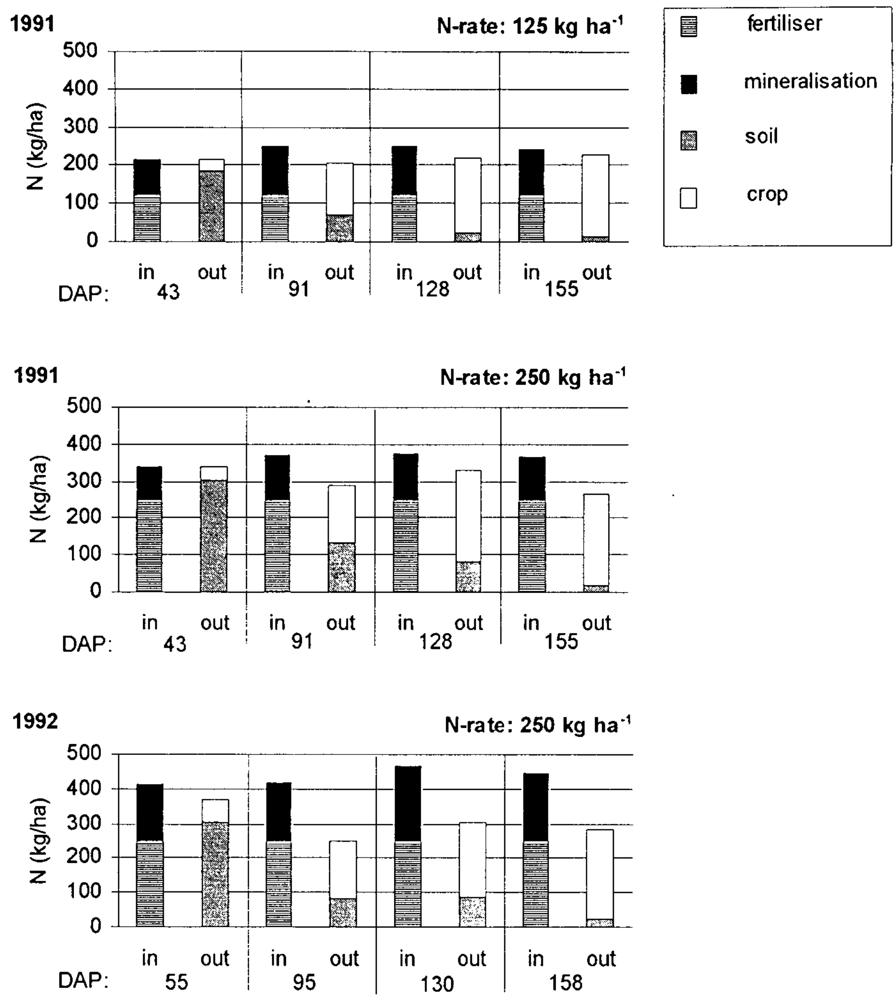

Figure 3: The nitrogen input (mineralisation, fertilizer) and output (residual Nmin, crop) of leeks at different times (days) after transplanting (DAP), at different N-rates in 1991 and 1992.

Because only in leeks a deficit in the nitrogen balance developed the remaining part will only refer to leeks. The deficit in the balance was further examined to decide whether it was due to N losses to the environment. As an important potential loss is from leaching of nitrogen, we used the simulation model to estimate the contribution of leaching to this deficit. Using the actual N-uptake, precipitation + irrigation, temperature and observed LAI as main input variables in the model, the Nmin content of the soil (0-60 cm) and the leaching of mineral N from this soil compartment were simulated. The result was close to the measured Nmin values at the final harvest (Figure 4), and the simulated amount of N leached also approached the difference between N-input and N-output fairly well (Figure 3). However, the time course of leaching was not in agreement with the development of the deficit in the balance. In both years this deficit (Table 1), was much higher than the simulated amount of leached N at the beginning of September (approx. 90 DAP) (Figure 3). This difference disappeared during the remainder of the growing season, when the simulated leaching exceeded the deficit in the balance (Table 1, Figure 4).

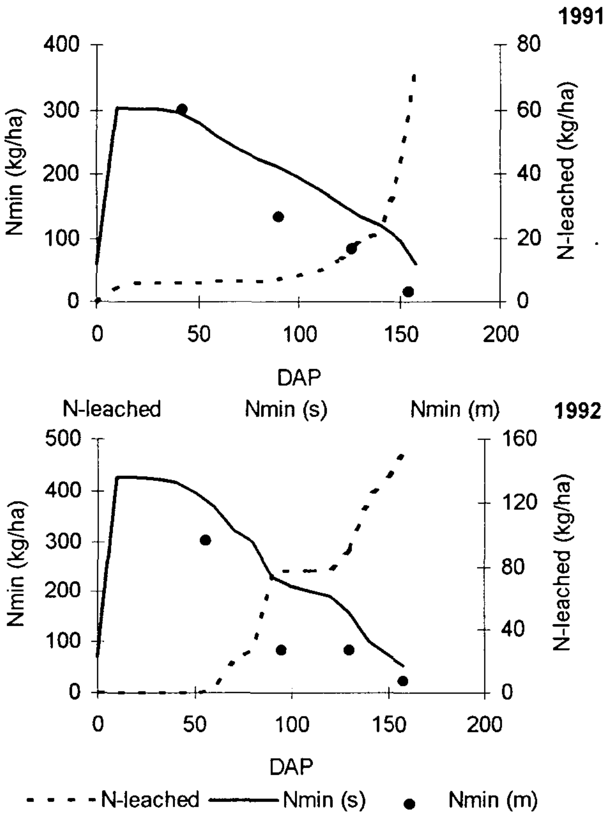

Figure 4: The simulated mineral nitrogen (Nmin(s)), the measured mineral nitrogen (Nmin(m)) in the soil layer 0-60 cm and the simulated cumulative amount of nitrogen leached from this soil layer during the growth of leeks in 1991 and 1992 following the application of 20 kg ha^{-1} N at transplanting.

To analyse the opportunities to reduce the losses because of leaching in leeks, we examined the effect of varying the timing of nitrogen application. An application of 250 kg ha^{-1} applied at transplanting resulted in a high N-deficit in the balance (Table 1). By splitting the amount into 125 kg ha^{-1} at transplanting and 125 kg ha^{-1} at the beginning of September (approx. 90 DAP), the total N-deficit was reduced (Table 1). However, if the amount of 250 kg ha^{-1} was split, the deficit mainly built up after the second application (Table 1). Only after a single application of 60 kg ha^{-1} at the beginning of September no N-deficit was observed (Table 1).

Table 1: The effect of N application rate and time of application on the fresh shaft weight of leeks, the nitrogen percentage in the leaf dry matter, the N-uptake by the crop until the beginning of September (I) and between the beginning of September and the final harvest (II), the N-deficit in the balance at the beginning of September (about 90 DAP) and at the final harvest.

Year	N- rate ($kg\ ha^{-1}$)	Fresh shaft weight (g/ plant)	%N (leaves)	N-uptake period I	N-uptake period II	N-deficit at 90 DAP	N-deficit at the final harvest
1991	0	161	2.2	91	15	0	0
	125	203	2.9	137	75	43	15
	250	212	3.2	156	95	84	98
	LSD 0.05	32					
1992	0+0*	196	2.5	142	37	0	0
	0+60*	207	3	142	96	0	-3
	0+90*	195	2.9	142	82	0	36
	125+125*	207	3.6	179	93	42	129
	250+0*	210	3.1	165	94	169	163
	LSD 0.05	46					

* Amounts applied at transplanting + at the beginning of September (approx. 90 DAP)

In addition to these potential losses to the environment, the effect on yield and quality should also be considered. In 1991, withholding nitrogen resulted in a significant lower fresh shaft weight, which was unaffected by applications between 125 kg ha^{-1} N and 250 kg ha^{-1} N (Table 1). In 1992 there was no significant effect of nitrogen application rate or timing of application, on fresh shaft weight (Table 1), so in spite of the low mineral nitrogen content at the beginning of September of 1992 in the unfertilized plots (Figure 1), no reduction of the final yield was found (Table 1).

The green colour of the leaves is an important quality characteristic of the marketable product in leeks. The green colour of the leaves is highly correlated with the chlorophyll content of the leaves, which can be estimated using the SPAD-meter (Wood et al., 1992). Our results showed that this SPAD-value was highly correlated with the nitrogen percentage in the leaves (Figure 5). This nitrogen percentage increased with increasing nitrogen application rate, when all nitrogen was applied at transplanting (Table 1). A late application of nitrogen increased the nitrogen concentration of the leaves with the split application of 250 kg ha^{-1} giving the highest value. An application of 60 kg ha^{-1} at the beginning of September gave a similar value as an application of 250 kg ha^{-1} after transplanting (Table 1).

4. Discussion

Our results show; that deficits on the nitrogen balance can occur during the growing season and that these deficits were higher in the crop with a slow N-uptake rate (leeks) than in the crop with a high N-uptake rate (Brussels sprouts) (Figures 1, 2, 3). According our simulations the deficit on the nitrogen balance at the final harvest could be attributed mainly to leaching of nitrogen (Fig. 4). However, the development of the deficit and the timing of nitrogen leaching did not coincide (Figures 3, 4). The asynchrony of the deficit in the balance and the simulated nitrogen leaching could be attributed to:

1. A difference in the release of nitrogen by mineralisation from organic matter between fertilized and unfertilized fields, which would invalidate the calculations.
2. Nitrate was temporarily immobilised.
3. Shortcomings in the simulation model due to possible shortcomings in the soil processes affecting nitrogen availability.

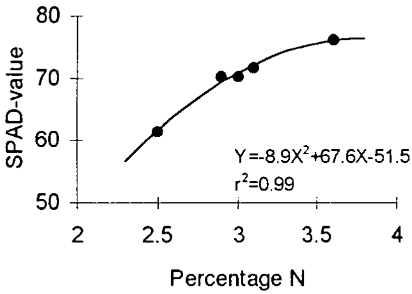

Figure 5: The relationship between the nitrogen percentage in the dry matter of leaf blades of leeks and the SPAD-value. Data are from the final harvest in the 1991 experiment (all treatments).

We can not conclude which one was determining, but the phenomenon was not accidental as it was observed in both years (Figures 3, 4).

Although in Brussels sprouts the deficits on the nitrogen balance were small, the amount of nitrogen in the crop residue is high (Booij et al., 1993) and forms a potential risk for losses by leaching after harvest . Losses from the breakdown of the crop residue depends on the time of harvest and the composition of the material (Whitmore and Groot, 1994).

Residual mineral nitrogen in the soil at the final harvest is amenable to leaching during winter (Greenwood, 1990). In our experiments the residual Nmin was low in all situations (Figures 2 ,3). This is due to the rapid uptake in Brussels sprouts and to pre-harvest losses from the rooted soil in leeks. To minimise the residual nitrogen in the soil, KNS was developed in Germany to provide recommendations for nitrogen fertilization (Lorenz et al., 1989). In the KNS management system, nitrogen fertilizer is applied during growth taking into account the expected N-uptake in the next period and the Nmin at the time of sampling. The difference between the expected nitrogen uptake and the available Nmin should be applied as fertilizer, after an adjustment for the minimum Nmin. This so called N-buffer is the amount of mineral nitrogen in the soil that should be kept until the harvest, to obtain optimum yield. For leeks this value is 60 kg ha^{-1} N in the soil layer 0-60 cm (Lorenz et al., 1989). In our leeks experiments the Nmin was low at the final harvest after all application rates in both years (Figure 1). However, only in 1991 a reduction in fresh shaft yield was observed when no nitrogen was applied (Table 1). So there was no relationship between the residual nitrogen at the final harvest and yield. Although the Nmin was also low at the beginning of September in both years (Figure 1), only in 1991 there was a significant effect of fertilizer rate on yield (Table 1). If the mineral N content in the soil is low, the N-uptake rate is determined by the mineralisation rate. However, the mineralisation rate, as determined by N-uptake from the unfertilized plot, was only slightly higher during the last part of the growing period (Table 1) in 1992 and not sufficient to explain the difference between both years. This means that both the Nmin and the mineralisation rate during the last part of the growing season (from the beginning of September) determined the final yield.

The amount of nitrogen taken up before the beginning of September, was much higher in the unfertilized field in 1992 than in 1991 (Figure 1). A higher nitrogen content at the beginning of September also coincided with a higher leaf area, as nitrogen uptake is linearly related with the leaf area index (Booij et al., 1996). This results in a higher light interception during September and October and therefore in a higher dry matter production (Booij et al., 1996). So the lower yield in 1991 in unfertilized plots is more likely to be due to insufficient leaf area at the beginning of September, than to the low Nmin because of the lower earlier mineralisation rate.

In conclusion, the earlier mentioned N-buffer, which should be maintained until the final harvest to obtain optimal yield does not seem to be necessary in leeks.

In addition to physical yield, marketable yield quality also plays an essential role. We have shown that the green colour could be maintained by a late nitrogen application, resulting in a higher nitrogen concentration in the leaves (Figure 5, Table 1), without significant losses to the environment. Analysis of the results in the present experiments showed, that 125 kg ha^{-1} was sufficient in 1991 and 0 kg ha^{-1} in 1992, to reach optimal yield (Table 1). Recommended application rates (270-Nmin) were 200 kg ha^{-1} in both years (Smit and Van der Werf, 1992), although the recommended rates aim to optimise marketable yield, which is a combination of yield, quality and usual losses. Our results show that if these three aspects are recognised and nitrogen is applied in accordance with the requirements in time for each, environmentally sound production of leeks is possible.

Acknowledgements

We want to thank Dr I.G. Burns and Dr A.J. Haverkort for their valuable comments on the manuscript.

References

Booij, R., C.T. Enserink, A.L. Smit and A. Van der Werf, 1993: Effects of nitrogen availability on crop growth and nitrogen uptake of Brussels sprouts and leek. Acta Hortic. 339: 53-65.

Booij, R., A.D.H. Kreuzer, A.L. Smit and A. Van der Werf, 1996: Effect of nitrogen availability on dry matter production, nitrogen uptake and light interception of Brussels sprouts and leeks. Neth. J. Agric. Sci., in press.

Greenwood, D.J., 1990: Production or productivity, the nitrate problem? Ann. appl. Biol. 117: 209-231.

Hähndel, R. and K. Isermann, 1993: Soluble nitrogen and carbon in the subsoil in relation to vegetable production intensity. Acta Hortic. 339:193-206

Hansen, J.F., 1989: Nitrogen balance in agriculture in Denmark and ways of reducing the loss of nitrogen. In: J.G. Germon (ed.). Management systems to reduce impact of nitrates, Elsevier applied Science, London, pp. 1-15.

Heinen, M. and P. de Willigen, 1992: FUSSIM2. A simulation model for two-dimensional flow of water in unsaturated soil. Nota 260, Institute for Soil Fertility, Haren. 146 pp.

Huggins, D.R. and W.L. Pan, 1993: Nitrogen efficiency component analysis: an evaluation of cropping system differences in productivity. Agron. J. 85:898-905.

Lorenz, H.P., J. Schlaghecken, G. Engl, A. Maync, J.Ziegler, M. Kohl and K. Strohmeyer. 1989: Ordnungsgemässe Stickstoff-Versorgung im Freiland-Gemüsebau nach dem "Kulturbegleitenden Nmin-Sollwerte (KNS)-System" Ministerium für Landwirtschaft, Weinbau und Forsten, Rheinland Pfalz, Mainz, 85 pp.

Neeteson, J.J. and W.P. Wadman, 1987: Assessment of economically optimum application rates of fertiliser N on the basis of response curves. Fert. Res. 12:37-52.

Smit, A.L. and A. Van der Werf, 1992: Physiology of nitrogen uptake and utilisation. (In Dutch) In: H.G. Van der Meer and J.H.J. Spiertz (Eds.). Stikstofstromen in agro-ecosystemen. Agrobiologische Thema's no. 6, DLO-Centrum voor Agrobiologisch Onderzoek (CABO-DLO), Wageningen, pp. 51-69.

Wehrman, J. and Scharpf, H.C., 1989: Reduction of nitrate leaching in a vegetable farm: fertilization, crop rotation, plant residues. In: J.G. Germon (ed.), Management systems to reduce impact of nitrates, Elsevier applied Science, London, pp. 147-157.

Whitmore, A.P. and J.J.R. Groot, 1994: The mineralization of N from finely or coarsely chopped crop residues. Eur. J. Agron. 4:367-373.

Willigen, P. de, M. Heinen and B.J. Van den Broek, 1995: Modelling water and nitrogen uptake of a potato crop growing on a ridge. In: A. J. Haverkort and D.K.L. MacKerron (eds.) Potato ecology and modelling of crops under conditions limiting growth, Kluwer Academic Publishers. Dordrecht, pp. 75-88.

Willigen, P. de, and M. Van Noordwijk, 1989: Rooting depth, synchronization, synlocalization and N-use efficiency under humid tropical conditions. In: J. Van der Heide (ed.) Nutrient management for food production in tropical farming systems. Haren and Malang, Institute for Soil Fertility and Universitas Brawijaya, pp 145-156.

Willigen, P. de and M. Van Noordwijk, 1995: A model for interactions between water and nutrient uptake. In: P. Kabat, B. Marshall, B.J. van den Broek, J. Vos and H. van Keulen (eds.). Modelling and parametrization of the soil-plant-atmosphere system A comparison of potato growth models. Wageningen Press, Wageningen, pp. 135-153.

Wood, C.W., D.W. Reeves, R.R. Duffield and K.L. Edmisten, 1992: Field chlorophyll measurements for evaluation of corn nitrogen status. J. Plant Nutr. 15:487-500.