The effect of nitrogen fertilization on root distribution of winter wheat

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ABSTRACT

The effect of nitrogen fertilization on root length (RL) distribution of winter wheat (*Triticum aestivum* L.) was investigated. The study was conducted in Prague-Ruzyne on clay loam Chernozemic soil in the years 1996–2003. Two (N0, N1) and three (N0, N1, N2) treatments, unfertilized (N0), fertilized with 100 kg (N1) and 200 kg N/ha (N2) were studied in 1996–2000 and 2001–2003, respectively. Nitrogen rate 100 kg/ha had no effect on RL in soil layers ($P > 0.1$) in years 1996–2000 and 2002–2003 and there was not significant interaction between N treatment and soil layer except for year 1998 ($P < 0.01$). Nitrogen fertilization affected RL distribution significantly ($P = 0.013$) only in 2001 due to reduction of root growth in subsoil layers in treatment N2 (200 kg N/ha) in comparison with N0 and N1. The effect of N fertilization on total RL in rooted soil volume was insignificant. There was a significant effect of year on total RL ($P < 0.01$) but not of interaction of year and N treatment. Roots reached, with the exception of two years, the depth between 100 and 130 cm. Nitrogen fertilization (N1) had no effect ($P = 0.59$) on rooting depth (RD) in years 1996–2000 but there was a significant effect of interaction between year and N fertilization on RD ($P < 0.01$). In the second experimental series (2001–2003) N fertilization rate 200 kg N/ha significantly reduced maximum RD ($P < 0.01$) in comparison with N0 and N1. The year had highly significant effect on RD.

Keywords: root length; distribution; rooting depth; nitrogen; subsoil; *Triticum aestivum* L.

Root growth and other characteristics as the rate of growth to depth, root density (root length per soil volume) and maximum rooting depth indicate a supply of potentially available mineral nitrogen and water in subsoil for crops (Kuhlman et al. 1989, Svoboda et al. 2000, King et al. 2003). While mineral N in densely rooted topsoil and shallow subsoil to about 40–50 cm is easily available, uptake of nitrogen and water from sparsely rooted subsoil may be limited by the rate of ion transport to root surface. Thus, management practices which have direct or indirect effect on root density in subsoil may change the ability of a crop to deplete deep soil horizons. A concern exists that a high doses of nitrogen decrease growth to depth and root density in subsoil as crop demand for N is saturated from enriched top soil layer. In hydroponic, pot and field experiments with wheat and other cereals increasing nitrogen supply enhanced both shoot and root growth, but usually shoot growth more than root growth, leading to increased shoot/root dry weight ratio with increase in N supply (Robinson et al. 1994, Marschner 1995, Lucas et al. 2000). At high N rates inhibition of root mass and/or length was observed (Welbank et al. 1974, Feil and Geisler 1988). Further, the stimulating effect of increased local concentration of nitrate-N on uptake and root proliferation may affect root distribution in a soil (Drew 1975, Robinson 1996).

The maximum depletion of N from subsoil layers is desirable from both, economical and environmental reasons. Therefore, possible agro-technical measures for manipulation of root distribution are of interest (Haberle et al. 2004). However, it is hindered by a lack of data on root density in subsoil layers and also little is known about the year-to-year variation in rooting depth.

The objective of the study was to determine the effect of nitrogen fertilization on root length distribution in the soil profile and on rooting depth of winter wheat.

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MATERIAL AND METHODS

The distribution of roots in a soil profile was studied in the field experiment with winter wheat (*Triticum aestivum* L.) cv. Samanta in years 1996–2000 and cv. Nela in 2001–2003. The cultivars belong to the same grain quality group (A), both exhibit a good spring regeneration, tillering, plasticity and yield stability; cultivar Nela is by 10 cm shorter (85 cm) than Samanta (95 cm). The content of mineral N ($N_{min} = N\text{-}NO_3^- + N\text{-}NH_4^+$), soil moisture, crop growth and nitrogen uptake were determined several times during the growth in the experiment (Haberle and Svoboda 2000, Svoboda et al. 2000, Haberle et al. 2002, Haberle et al. 2006).

The experiment was conducted in Ruzyne near Prague, altitude 340 m a.s.l., normal precipitation and temperature (1961–1990): 477 mm per year and 7.9°C, respectively. Month precipitation and average temperature are shown in Figure 1. The experiment field is a deep clay loam Chernozemic soil on loess. Basic agrochemical data and the texture of soil layers are given in Tables 1 and 2. The wheat was included in three-year crop rotation; preceding crops were one-year lucerne or woolly blue curls in seasons 1996–1999 and yellow mustard in 2000–2003. The field was regularly fertilized with P and K to preceding crops, no organic fertilizers besides crop residues were used during the experiment.

Two treatments were observed in years 1996–2000; N0 – unfertilized and N1 – fertilized with 100 kg N/ha, split applied in spring in ammonium nitrate. From the season 2000/2001 the treatments N1 and N2 were fertilized with 100 kg N/ha in calcium nitrate before winter to increase nitrate content in subsoil in spring. In spring the dose 100 kg N/ha in ammonium nitrate was split applied in treatment N2. The experimental field was arranged with 6 replicates (plots 5.5 × 6 m).

Soil with roots was sampled with soil sampler (diameter 3.4 cm) in 10 cm increments to the depth of 10–20 cm under where the roots could be found. There were six replicates per treatment, four taken under the row of plants an two between rows, the distance between row being 12.5 cm. Preliminary analysis showed no effect of sampler position on root length under 20 cm. Roots were sampled after anthesis (DC 71-75) in all years, except for year 1997 when sampling had to be done in DC 61 due to organizational problems. Roots were washed from soil, cleaned and length was determined after Tennant (1975).

Root density for individual layers was calculated from sampler volume and root length (RL), the results were expressed in cm/cm^3 and in km/m^2. The bottom of the last layer where roots were found is denoted as the maximum rooting depth (RD), the layer under which an average root density dropped under 0.5 cm/cm^3 as the effective rooting depth.

The effect of nitrogen fertilization on RL distribution and RD was evaluated by two-way analysis of variance (ANOVA). LSD test was used to evaluate the differences among treatments in individual layers.

RESULTS AN DISCUSSION

In the contribution results of eight-year field experiment aimed at the effect of nitrogen fertilization on wheat root length distribution in soil profile are presented.

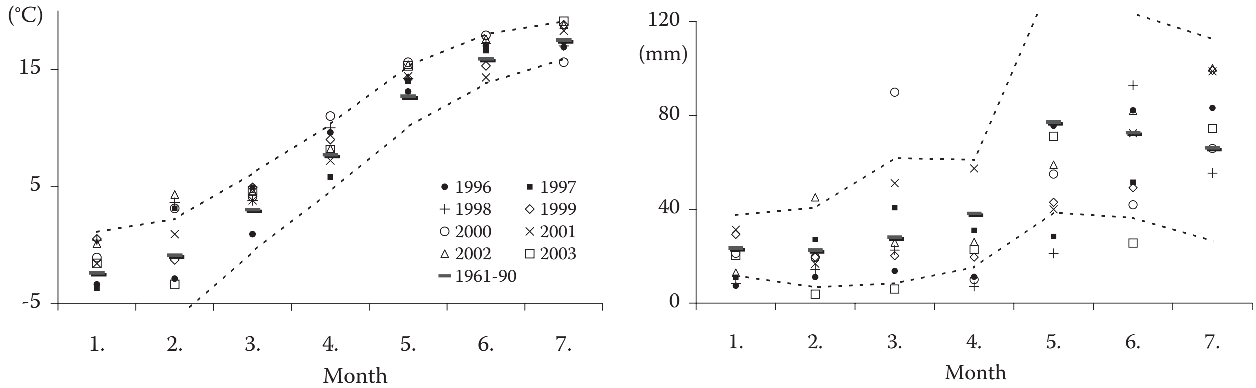

Figure 1. The average temperature and precipitation in 1996–2003 in Prague-Ruzyne; normal (1961–1990) monthly temperature and precipitation are shown; dotted lines separate above and very above normal values and below and very below normal values of monthly temperatures and precipitation (Kožnarová and Klabzuba 2001)

Table 1. Soil texture and physical characteristics of the experimental field

Depth (cm)	Clay content < 0.01 mm (%)	Coarse fraction 0.1–2 mm (%)	Soil density (g/cm^3)
0–30	52.6	8.3	1.30
30–50	56.0	5.4	1.43
50–70	52.1	9.2	1.55
70–90	50.7	13.4	1.55
90–120	55.9	13.2	1.65
120–150	53.8	18.7	1.60

Table 2. Basic agrochemical data of the experimental field

Depth (cm)	K* (ppm)	P* (ppm)	Mg* (ppm)	pH (KCl)	C_{ox} (%)	N_{tot} (%)
0–30	245	85	226	7.0	1.5	0.087
30–70	141	12	254	7.3	0.8	0.055
70–110	121	10	352	7.3	0.6	0.044
110–150	81	2	168	7.3		

*Mehlich 3

Different types of weather occurred during the experiment, from cold and wet to dry and hot, that increases the reliability of obtained data. Generally, the years 1998, 2000, 2002 and 2003 were dry and mostly hot during the main growth period of wheat roots (approximately mid March-mid June), the year 1997, 1999 and 2001 were rather wet and/or cold (Figure 1). To find a possible relation between weather conditions and root growth is not simple, as it may be affected adversely by both drought and excess of water or stimulated by a mild water shortage.

The effect of N fertilization and the year on root length distribution

The effect of nitrogen fertilization (N1) on RL in soil layers was not significant (P = 0.16 to 0.92) in the period 1996–2000 (Figure 2). The interaction between N treatment and soil depth was significant only in 1998 (P = 0.007) and in 1997 (P = 0.045). In 1997 and 1999 nitrogen fertilization slightly increased and in 1998 and 2000 decreased root density in subsoil layers but the effect was not significant. The statistical analysis was impaired by the opposite effect of nitrogen fertilization on root density in specific soil zones, especially in 1997 and 1998 (Figure 2). A high variability of root length in some cases was caused by the presence of biopores and, especially in top layers, by variation in local plant density and tillering.

The fertilization affected root density significantly only in 2001 (P = 0.013) due to reduction of root growth in subsoil layers in treatment N2 (200 kg N/ha). The differences between N0 and N1 were not significant. In the year 2001 there was an unusually high N_{min} content under 50 cm. Some trend to reduction of root length in N2 in subsoil was also apparent in 2002 and 2003 (Figure 2).

Consistently small effect of nitrogen fertilization rate 100 kg/ha in comparison with unfertilized control was probably caused by the fact that the dose did not fully satisfied the demand for N by wheat crop as showed by comparison of dilution curves (Svoboda et al. 2000). The notion is supported by a similar, extensive utilization of available N_{min} supply in N0 and N1 treatments (Haberle et al. 2006). Thus, the roots were stimulated to growth to a deep subsoil like in N0 treatment. In treatment N2 the N_{min} supply was excessive as shown by a high residual N_{min} content after harvest (Haberle et al. 2006).

Observed root densities generally agree with data observed elsewhere (e.g. Barraclough and Leigh 1984, Kuhlmann et al. 1989) but the comparison is impaired by different methods of root sampling and washing, and by a strong effect of soil and climate conditions on root traits. There is not relevant data available from the Czech Republic for the comparison. We found the same root distributions and a small effect of nitrogen fertilization on winter wheat cv. Siria grown in adjacent plots in years 1997–2000 (not shown).

The root density decreased approximately exponentially from top arable layers to deep layers as observed in many experiments with winter wheat and other crops (Qiang et al. 2004). However, the regression model can be hardly used for estimation of root density in a deep subsoil and of maximum rooting depth as there were evident deviations from smooth decay trend (Figure 2).

The effect of nitrogen fertilization on the total root length and rooting depth

The total root length (RL) in rooted profile moved in a wide range, between 16.5 km and 44.8 km/m^2

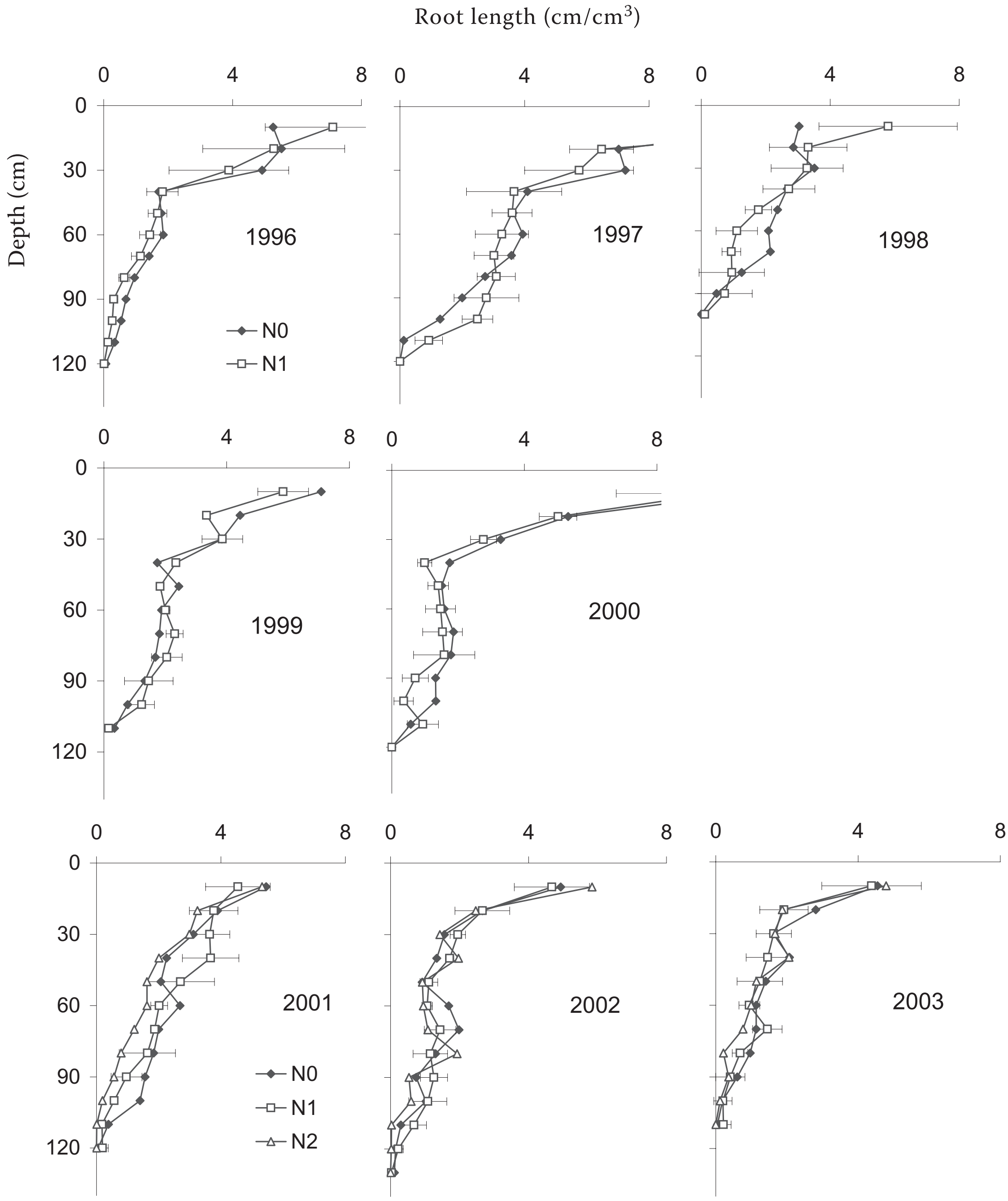

Figure 2. Root density of winter wheat crop (in cm/cm^3); only standard errors of treatment N0 are shown to improve readability of graphs

in N0, 14.5 km and 49.9 km/m^2 in N1 in years 1996–2003 and between 13.9 and 19.6 km/m^2 in N2 in years 2001–2003. The observed RLs correspond to published data for winter wheat but the comparison is not easy as the data are also in a wide range. The exceptionally high RL in 1997, 47.8 and 49.9 km/m^2, was probably caused by a combination of a high content of N_{min} in subsoil, optimal soil moisture and uniformly distributed precipitation (Figure 1) stimulating progressive depletion of soil reserves by roots from top to subsoil zones (Haberle and Svoboda 2000), vigorous tillering and a long survival of no productive tillers.

Similarly to root density, the effect of N fertilization (N) on total root length was insignificant irrespective of whether all experimental years (P = 0.26) or separately, the results of the period 1996–2000 (P = 0.48) and 2001–2003 (P = 0.17) were analysed. There was a significant effect of year on total root length (P < 0.01) but not interaction of year and N treatment. We were not able to find a strong and consistent relation between RL or

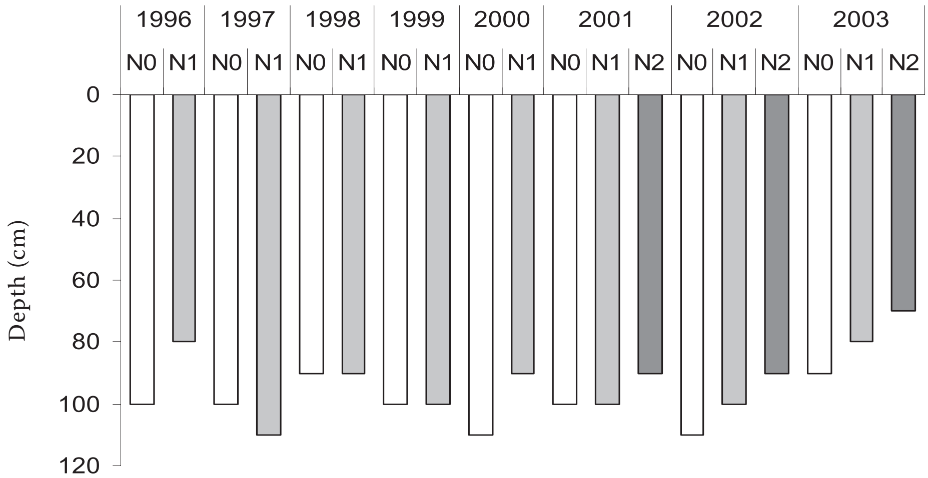

Figure 3. The average effective rooting depths (in cm)

rooting depth and weather indices or N_{min} content in the experiment.

The greatest rooting depth 130 cm was observed in 2002 (N0, N1) and the depth 120 cm was observed in 1996 and 2001 (N0, N1) and in 1997 (N1). The least rooting depth 70–100 cm was observed in 1998 that was characterized by an atypical delay of N uptake due to a dessication of topsoil (Figure 2). The year had highly significant effect on rooting depth, nitrogen fertilization had no effect ($P = 0.59$) on rooting depth in years 1996–2000 but there was an interaction between year and N fertilization ($P < 0.01$). In the second experiment (2001–2003) fertilization significantly affected maximum rooting depth ($P < 0.01$) thanks to the reduction of rooting depth in N2. The LSD showed that there was significant difference between N0 or N1 and N2 but not between N0 and N1.

The root density 1.0 cm/cm^3 and other values were proposed as a lower limit for effective nitrogen or water uptake from subsoil layers (e.g. Burns 1980) but the term refers to root density that is not capable to sustain sufficient uptake to cover plant demand. Other studies showed that water and nitrogen can be extracted from deep layers thanks to increase of root uptake capacity, mass flow and diffusion of nitrate to roots (Kuhlman et al. 1989, Sauer et al. 2002). Still, such value may serve as an indicator of the depth where root density should not limit uptake. We calculated effective rooting depth where root density dropped under 0.5 cm/cm^3; it ranged from 90 to 110 cm, 80 to 110 cm and 70 to 90 cm in N0, N1 and N2 fertilization treatments (Figure 3). Similarly to maximum depth there was no significant effect ($P = 0.37$) of fertilization in 1996–2000 but a significant one ($P = 0.009$) in 2001–2003. The year had a highly significant effect on effective rooting depth only in 2001–2003. Most authors found that roots of cereals grow quickly to depth in relation to thermal time during tillering and stem elongation (e.g. Barraclough and Leigh 1984, King et al. 2003, Smit and Groenwold 2005) and rooting depth or root density reach the highest values about anthesis. Still, we cannot exclude the possibility that roots grew some 10–20 cm deeper after sampling term in some years.

The small differences of root density in subsoil or of root depth between treatments N0 and N1 are probably not able to affect substantially distribution of nitrogen uptake. The rate 200 kg/ha decreased significantly root density in subsoil and rooting depth but the effect was strong only once in three years. The results suggest that under soil and climate condition of experimental site reasonable nitrogen fertilization should not affect a potential ability of wheat crop to extract nitrogen or water from deep subsoil. It is evident that root growth in deep subsoil will be important for uptake when there is not enough available nitrogen in above layers and *vice versa*.

The results of the field experiment showed that rate of nitrogen fertilization 100 kg/ha did not significantly affected root depth and root length in the soil profile while a high rate of 200 kg N/ha reduced root growth in subsoil in some years.

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