Factors affecting nitrogen concentration in spring oilseed rape (*Brassica napus* L.)

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ABSTRACT

The effect of the duration of the growth season, meaning daily temperature, precipitation rate, growing degree in days, nitrogen rates and application time, stand population density, soil nitrogen content and the interaction among these factors on nitrogen concentration in spring oilseed rape plants of aboveground dry matter. During the vegetative growth season, mature seeds and straw were studied in field experiment with spring oilseed rape (*Brassica napus* L.) cv. Star over five years. It was found that nitrogen concentration was the highest in the youngest plants. The increase of duration in growth season and precipitation rate had a negative effect on nitrogen concentration in mature seeds. Meanwhile, the increase in growing degree-days and mean daily temperature positively affected seed nitrogen concentration. The relationships between nitrogen concentration in spring oilseed rape plants at different growth stages and climate records was found. Stand population density occurred having a rather negligible effect on nitrogen concentration. Nitrogen fertilizer rates showed strong and positive effect on nitrogen concentration in aboveground dry matter as well as in seed and straw. With the delay of nitrogen application time concentration of nitrogen was increasing.

Keywords: spring oilseed rape; nitrogen concentration; nitrogen rate; nitrogen application time; stand population density; mean daily temperature; precipitation rate; growing degree-days

Almost all investigations showed that nitrogen fertilizers gave substantial oilseed rape seed yield increases even in diverse and contradicting conditions (Maroni et al. 1994, Sieling and Christen 1997). However, fertilizer nitrogen requirements can differ very much according to soil type, climate, management practice, timing of nitrogen application, cultivars and etc. (Holmes and Ainsley 1977, Kalkafi et al. 1998). Uptake of nitrogen by oilseed rape crops is very high and in total may be over 250 kg N/ha (Geisler and Kullmann 1991, Grant and Bailey 1993). However, a great variation in nitrogen uptake by rape was noticed (Holmes 1980). Nitrogen concentration in plant dry matter during the vegetative growth period as well as in mature seed and straw depends on nitrogen content in the soil, fertilizer rates and timing, weather conditions, stand population density, cultivars, plant development stages and other factors. It was showed that nitrogen concentration of oilseed rape plants, expressed as a percentage of dry matter, is the highest at the rosette stage, when most of the dry matter is in the leaves and falls steadily thereafter (Holmes 1980, Hocking 2001). On average the leaves of winter oilseed rape had a nitrogen content of 3.0–4.8% in the autumn, falling to between 1.2–1.9% at seed maturity (Holmes 1980).

The nitrogen content in oilseed rape mature seed and straw can vary over a wide range, even in crops receiving adequate nitrogen fertilizer (Holmes 1980). Individual crops adequately fertilized within the limited geographical area exhibit a range of nitrogen concentration in seed from 3.35–5.14% (Holmes and Ainsley 1977). Perhaps differences in environmental and husbandry conditions can provide some explanation for this variation. Nitrogen concentration in oilseed rape straw is much lower as compare to seed and mainly is in range of 0.5–0.8%, reflecting the transfer of the most of the nitrogen to the seed (Holmes 1980).

There is little reported about the effect of environmental factors on nitrogen concentration in oilseed rape dry matter as well as in seed and straw. It was showed that increased soil moisture supply increases the total dry biomass and seed yield potential of the oilseed rape and increases the amount of nitrogen required for optimum yields (Bailey 1990). However, it was found that the lowest nitrogen content in winter oilseed rape was in the worse climate conditions with high precipitation rate (Balik et al. 1995). It was suggested that cool and wet weather which leads to higher chlorophyll level through late maturity also leads to the lowest level of nitrogen concentration (Daun and Douglas 1995).

It was reported that large quantities of available nitrogen prolonged the vegetative growth stages and increased the accumulation of dry matter and plant nitrogen (Bailey 1990). The relationship between nitrogen rate and plant nitrogen content seems obvious; the more nitrogen applied the greater is plant nitrogen content (Yusuf and Bullock 1993). However, this relationship could vary depending on soil, cultivar, meteorological conditions, agronomic practice, stand population density, nitrogen application time and other factors.

The competition among individual plants can influence oilseed rape seed yield (Mendham et al. 1981a, Morrison et al. 1989). It was found that nitrogen concentration in oilseed rape dry matter tended to increase with increased nitrogen supply and decrease with increased seeding rate (Gramshaw and Crofts 1969). However, the effect of the treatments and an interaction between them on nitrogen concentration was relatively small.

The objectives of this study were to investigate the effect of the mean daily temperature (MDT), precipitation rate (PR), duration of growth stages, nitrogen rate and timing, stand population density (SPD) and interaction. Among these factors on nitrogen concentration in spring oilseed rape plants during the vegetative growth period as well as in mature seed and straw under the moderate climatic conditions.

MATERIAL AND METHODS

Spring oilseed rape cv. Star was grown on Endocalcari – Epihypogleyic Cambisols soil at the Lithuanian Institute of Agriculture in Dotnuva-Akademija. Soil samples were collected before sowing from 10 cores in each block, and the composite samples were prepared for soil analyses. Chemical properties of the arable layer (0–25 cm) were: N total 0.132–0.181% (Kjeldahl technique after distillation) (Official Methods of Analysis 1984); P = 78.5–95.9 mg/kg soil; K = 141.1–174.3 mg/kg soil (A-L method) (Egner et al. 1960). Soil pH_{KCl} ranged from 6.4 to 7.2.

Spring oilseed rape according to meteorological conditions was sown between April 28 and May 12 between 1993–1997 with the interrow spacing of 12.5 cm. The experiment included three seeding rates of 4, 7 and 10 kg/ha. Ammonium nitrate (34.5% N) was broadcasted at drilling, at 4–5 leaf stage, and at the start of flowering. Each application date included five one-time applied nitrogen rates: 0, 60, 120, 180 and 240 kg/ha. Single granular superphosphate (39.2 kg P/ha) and potassium chloride (99.6 kg K/ha) were broadcasted at drilling. Plots were arranged in a split – split – plot completely randomized design with three replications. Seeding rates were the main plots, nitrogen application times – sub – plots, and nitrogen rates – sub – sub – plots. The three-year crop rotation included spring barley, winter wheat, and spring oilseed rape.

After full germination plants of 1 m^2 area from each plot were counted for determination of stand population density. The second count was made after harvesting the plots counting left stubbles from the area unit. The shoots of ten plants per plot were harvested at 4–5 leaf stage, at the start and end of flowering, and at seed development stage. Sampled plants were dried at 65°C and then weighed. Total nitrogen concentration in plant materials as well as in mature seed and straw were determined using Kjeldahl technique (Official Methods of Analysis 1984).

Plots were harvested in late August or early September. Seed yield was determined from each plot at 8.5% moisture content.

Meteorological data records were obtained from the Agrometeorological Station on the site. Temperature sums with a baseline temperature of 5°C were expressed as growing degree-days (GDD).

Analysis of variance was used to test significance of treatment effects and interactions. Fisher's Protected Least Significant Difference method was used to determine significant differences between means (*$P \leq 0.05$ and **$P \leq 0.01$). Statistical analysis was completed using Statistica 5.5 version (Statistica System Reference 2001).

RESULTS AND DISCUSSION

Growth stages

Nitrogen concentration expressed on aboveground plant dry matter basis was the highest at 4–5 leaf growth stage and decreased steadily thereafter (Table 1). Similar results were obtained in other experiments showing that the highest nitrogen accumulation found in young plants was decreasing markedly with plants growth

Table 1. Nitrogen concentration in spring oilseed rape plant of aboveground dry matter at different growth stages, mature seed and straw

Nitrogen concentration (%)					
4–5 leaf	start of flowering	end of flowering	seed development	seed	straw
5.57 ± 0.611	4.05 ± 0.346	1.80 ± 0.015	1.02 ± 0.320	3.83 ± 0.247	0.63 ± 0.173

(Hocking 2001). The highest determined nitrogen concentration 5.57% at 4–5 leaf stage declined to 4.05% at the start of flowering (only the first flowers opened on the main raceme). During the flowering nitrogen concentration decreased from 4.05 to 1.80% at the end of flowering (only few flowers opened on lateral branches). In the experiment in Denmark was clearly shown that the highest nitrogen concentration among individual plant organs was found in the leaves, pods and seeds and the lowest in the stems and root dry matter (Schultz 1972). In accordance with these findings nitrogen concentration during the flowering decreased very rapidly due to the increase of the number of dropped off leaves, very rapid extension of the main raceme and the growth of lateral branches just before and during flowering. In spite of that pods and seed growth and development at the end of flowering is already started these newly formed organs with comparatively high nitrogen content contribution is too small to make greater effect on nitrogen concentration decreasing process in the whole plant aboveground dry matter.

The decline of nitrogen concentration in aboveground dry matter during the end of flowering and seed development stage was found much less obvious as compare to period of flowering. This could be the result of the physiological changes in plant individual organs growth, development and maturing cycle. At seed development stage the extension of the main raceme is already complete, leaf contribution in plant dry matter is very small as most of them is being dropped off at this time but pods and still maturing seed is expanding their contribution in plant dry matter content. Possibly high nitrogen concentration in pods and seeds resulted in less rapid decrease of nitrogen concentration at the seed development stage.

It was found that nitrogen concentration in mature seed and straw can vary over a wide range, even in crops that received adequate nitrogen fertilizer (Holmes 1980). According to the data published nitrogen content in seed and straw received moderate or high fertilizer nitrogen rate ranged respectively from 3.35 to 5.14% and from 0.80 to 1.80% (Holmes and Ainsley 1977, Stabbetorp 1973). On average in the experiment nitrogen concentration in mature seed was found 3.83%. Reflecting the transfer of most of the nitrogen to the seed nitrogen concentration in straw (0.63%) was much less as compare to the seed.

According to data obtained it is clear that nitrogen is decreasing steadily with the growth of the plant. However, during the years of the experiment, variation of the nitrogen concentration in the plant dry matter at tested growth stages as well as in seed and straw was noticed. Some explanation of differences in the plant nitrogen concentration could be provided by analysing environmental conditions and used husbandry practice.

Weather conditions

Meteorological records varied widely during the years of the experiment. The duration of spring oilseed rape vegetative growth period ranged from 101 calendar days (CD) in hot and dry 1994 to 124 CD in moderate cool and wet 1993. PR during the vegetative growth period ranged from 127.1 mm in 1994 to 418.7 mm in 1993. The lowest MDT of the whole growth season (14.1°C) was recorded in 1993. In 1994 and 1997 MDT was the highest (16.3°C). Accumulated by the plants growing degree-days (GDD) ranged from 1105.5 to 1321.2°C. Wide variation in climatic conditions was obvious also among growth stages.

It was found that oilseed rape grain yield positively correlated with total PR and negatively to mean maximum daily temperature for the months of July and August (Nuttall et al. 1992). However, there is little or no information available on how weather variables such as rainfall and temperature as well as agronomic factors can influence nutrient concentration during the vegetative growth season and yield.

Correlation analysis revealed that nitrogen concentration in mature seed negatively correlated to the number of CD and PR (Figure 1). It was found that the increase of growth season by each 10 CD decreased nitrogen concentration in mature seed by 0.2%. Nitrogen concentration in mature seed also decreased by 0.15% for each additional 100 mm of precipitation.

Nitrogen concentration in mature seed positively correlated to the MDT and GDD (Figure 1). It was determined that the rise in MDT of the vegetative growth period by 1°C increased nitrogen concentration in mature seed by 0.23%. Meanwhile, the increase of GDD by each 100°C increased nitrogen concentration by 0.25%.

Quite opposite tendencies as compare to seed were determined analysing nitrogen concentration in spring oilseed rape straw. The number of CD and PR from sowing till harvesting showed a positive effect on nitrogen concentration. These relationships were expressed with linear regression equations: $y_{days} = -0.556 + 0.011x$; $r = 0.54$; $y_{precipitation} = 0.344 + 0.0011x$; $r = 0.72$. Meanwhile, the increase in MDT tended to decrease nitrogen concentration in straw: $y_{temperature} = 2.195 - 0.101x$; $r = 0.53$. No relationship was found between nitrogen concentration in spring oilseed rape straw and GDD.

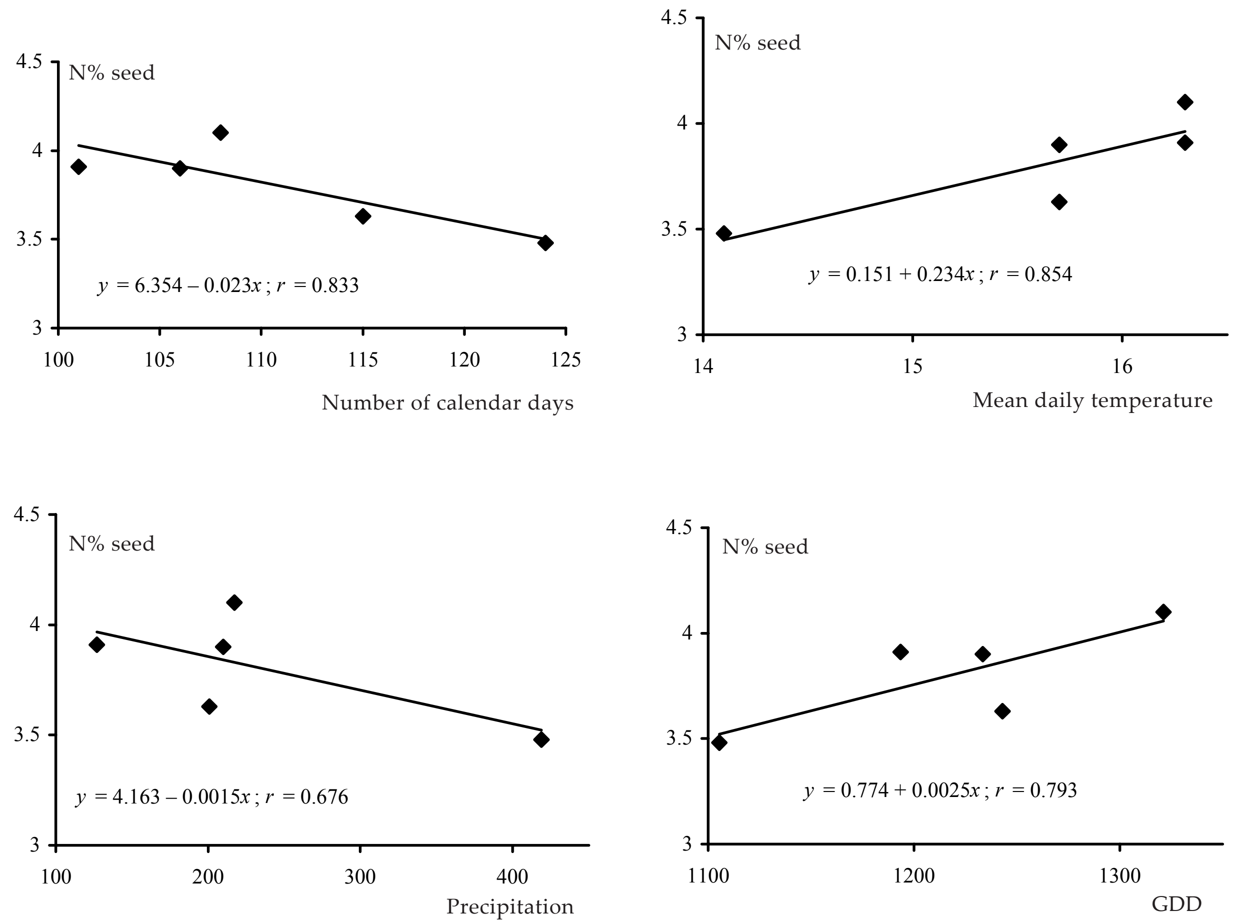

Figure 1. The effect of the duration of vegetative growth period (day), precipitation rate (mm), mean daily temperature (°C) and GDD (≥ 5°C) on nitrogen concentration in spring oilseed rape seed

However, as it happened in short – term experiments the influences of climate indices on nitrogen concentration in spring oilseed rape seed and straw was not statistically proved at 95% probability level ($P = 0.87$). Despite of that the obtained relationships could be good evidences of the influence of climatic conditions on the changes of nitrogen concentration in spring oilseed rape seed and straw.

Positive effect of MDT and GDD on nitrogen concentration in mature seed could be possible due to physiological process of the oil synthesis. When the seeds reached the maximum size the synthesis of proteins is slowing down meanwhile, the carbohydrates are becoming oils. So, when the growth period is getting longer the content of protein is decreasing meanwhile the oil content otherwise is increasing. Moreover, the lower air temperature and higher moisture supply in the soil is positively affecting the oil formation process as the synthesis of chlorophyll and the photosynthesis process is slowing down. Therefore the increase in duration of growth season and PR is negatively affecting the nitrogen concentration in spring oilseed rape seed. Meanwhile, the increase in MDT and GDD is showing a positive effect on nitrogen concentration in mature seed.

It was revealed that the duration, MDT, PR and GDD of growth stages also influenced nitrogen concentration in plants of aboveground dry matter at different growth stages. Duration of spring oilseed rape growth from sowing till 4–5 leaf stage, till the start and end of flowering and till seed development stage influenced nitrogen concentration in plants aboveground dry matter at different growth stages as well as in mature seeds and straw by 14.4–98.0%. The interaction between GDD and PR at different growth stages affected nitrogen concentration in plant dry matter, seeds and straw by 11.7–95.2%. However though the duration of growth stages, MDT, GDD and PR as well as the interaction among these factors noticeably influenced nitrogen concentration in oilseed rape plants during the growth season, seeds and straw. But not all variations of nitrogen concentration were consistent and could be explained by duration of growth stages, meteorological data or even by interaction among climate factors.

Stand population density

Rapeseed typically gives similar yields over a wide range of sowing rate (Mendham et al. 1981b, Nuttall et al. 1992). However, plants at higher density are thinner and carry fewer branches, crops growth rates and net assimilation rates are smaller. The individual leaf area per plant in the high density is 3–4 times smaller than in the low densities (Mendham et al. 1981b, Morrison et al. 1990). Therefore could be possible that stand population density can influence nitrogen concentration in plants and their yield. According to the data collected plants numbered per m^2 on an average ranging from 20 to 180. Though the influence of altering densities had rather small effect on nitrogen concentration it was statistically proven in all cases. Nitrogen concentration at 4–5 leaf stages increased from 5.21 to 6.23% where as stand population density increased from 27 to 121 plant/m^2. However, the changes in nitrogen concentration were inconsistent and differ from year to year. This relationship was expressed with first order equation: $y = 5.57 + 0.0057x$; $r = 0.35^{**}$. At the start of flowering stage nitrogen concentration in dry matter slightly increased with the increase of plant population density: $y = 3.859 + 0.0031x$; $r = 0.20^{*}$. It could be possible that the increase of nitrogen concentration at 4–5 leaf stage and at the start of flowering was affected by lower plants dry weight therefore the nitrogen concentration in plants dry matter tended to increase. Meanwhile, concentration

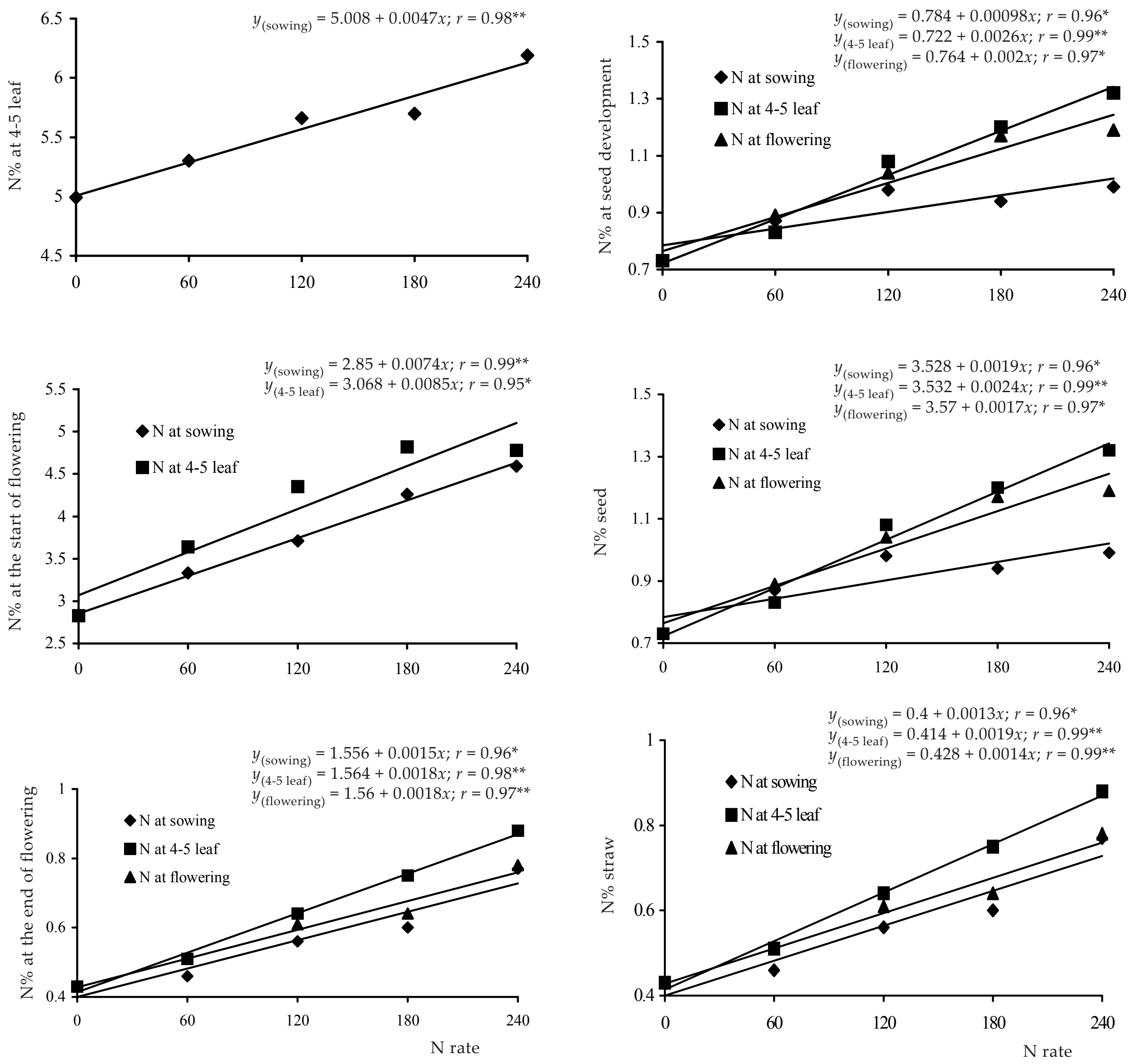

Figure 2. The relationship between N rate (kg/ha) and N concentration (%) in spring oilseed rape aboveground dry biomass at different growth stages, mature seed and straw

Table 2. The relationship among nitrogen concentration (y, N%) in spring oilseed rape dry matter during the vegetative growth and interaction between GDD (t, °C), precipitation rate (p, mm), nitrogen rate (r, N kg/ha) and total nitrogen content (n, N%) in 0–25 cm soil layer

N%	Regression equation	R^2 (%)
For the period from sowing till 4–5 leaf growth stage		
4–5 leaf	$y = 13.538 + 0.00834t_1 + 0.03609p_1 + 0.00424r – 91.682n$	85.76**
Start of flowering	$y = 2.903 + 0.01106t_1 + 0.02139p_1 + 0.00682r – 27.322n$	86.22**
End of flowering	$y = –0.138 – 0.00389t_1 – 0.00719p_1 + 0.00191r + 21.369n$	65.95**
Seed development	$y = –1.077 + 0.005t_1 + 0.01089p_1 + 0.00109r – 0.2076n$	84.39**
Seed	$y = –2.94 – 0.01163t_1 – 0.0013p_1 + 0.00202r + 70.987n$	85.72**
Straw	$y = –2.438 + 0.00031t_1 – 0.00356p_1 + 0.0012r + 21.656n$	51.21**
For the period from sowing till the start of flowering		
Start of flowering	$y = –8.384 + 0.00663t_2 – 0.00155p_2 + 0.00682r + 64.518n$	79.56**
End of flowering	$y = 5.209 + 0.00482t_2 + 0.00056p_2 + 0.00191r – 13.968n$	74.70**
Seed development	$y = –6.248 + 0.00249t_2 + 0.00015p_2 + 0.00109r + 43.337n$	71.97**
Seed	$y = 8.261 + 0.01071t_2 + 0.00588p_2 + 0.00202r – 9.436n$	90.79**
Straw	$y = –2.814 + 0.00242t_2 – 0.00188p_2 + 0.0012r + 18.067n$	52.64**
For the period from sowing till the end of flowering		
End of flowering	$y = 1.758 + 0.00062t_3 – 0.00356p_3 + 0.00191r – 0.876n$	73.19**
Seed development	$y = –5.052 + 0.00132t_3 – 0.00023p_3 + 0.00109r + 35.586n$	76.01**
Seed	$y = –1.141 + 0.00242t_3 – 0.00629p_3 + 0.00202r + 29.193n$	67.97**
Straw	$y = –0.023 – 0.00207t_3 + 0.00306p_3 + 0.0012r + 9.315n$	85.15**
For the period from sowing till seed development stage		
Seed development	$y = – 4.388 – 0.00007t_4 – 0.00055p_4 + 0.00109r + 37.959n$	71.48**
Seed	$y = 0.577 – 0.00186t_4 + 0.00202p_4 + 0.00202r + 24.085n$	66.41**
Straw	$y = – 1.396 + 0.00018t_4 + 0.00128p_4 + 0.0012r + 9.629n$	84.03**
For the period from sowing till maturity		
Seed	$y = – 0.078 + 0.00084t – 0.00152p + 0.00202r + 21.145n$	67.75**
Straw	$y = – 2.296 + 0.00088t + 0.00156p + 0.0012r + 9.106n$	87.26**

of nitrogen at the end of flowering slightly tended to decrease with the increase of stand population density: $y = 1.9001 – 0.0015x$; $r = 0.19$*. At the seed development stage nitrogen concentration in spring oilseed rape dry matter tended to increase than the number of plants per m^2 increased: $y = 0.6164 + 0.005x$; $r = 0.49$**. Concentration of nitrogen in mature seed tended to decrease with the increase in stand population density: $y = 3.963 – 0.0011x$; $r = 0.47$**. The effect of stand population density on nitrogen concentration in spring oilseed rape straw was weak and inconsistent.

Thus according to the statistical analyse of the collected data the effect of stand population density on nitrogen concentration in spring oilseed rape plants dry matter during the vegetative growth season as well as in mature seed and straw had rather small and inconsistent influence. In spite of that most of the relationships were statistically proved at 95% or even at 99% probability levels.

Nitrogen rate and timing

According to the data collected nitrogen fertilizer applied at sowing, at 4–5 leaf stage and at the start of flowering had very strong and consistent effect on nitrogen concentration in the spring oilseed rape plants dry matter at 4–5 leaf stage, at the start and end of flowering, at the seed development stage and in mature seed and straw (Figure 2). Nitrogen concentration was increasing with the increase of nitrogen rate from 0 to 240 kg/ha in spite of the time of application. However, nitrogen application time also had effect on concentration of nitrogen. In general the lowest nitrogen concentration was found when nitrogen fertilizer was applied at sowing.

With the delay of nitrogen application time till 4–5 leaf stage or even the start of flowering nitrogen concentration tended to increase. It is known that with nitrogen application at sowing plant weight and the number of lateral low-productivity branches is increasing (Allen and Morgan 1972). Therefore it is possible that when nitrogen fertilizer was applied at sowing most of it was used by plants to produce more vegetative mass and the concentration decreased as compare to nitrogen application at 4–5 leaf stage or at the start of flowering.

Multi regression analyse revealed that nitrogen concentration in spring oilseed rape plants dry matter during the vegetative growth season, mature seed and straw closely depends on interaction between nitrogen rate, total nitrogen content in 0–25 cm soil layer, GDD and PR (Table 2).

It was statistically analysed 150 cases of data with the aim to find the possibility for spring oilseed rape seed yield prognosis at early growth stages. It was found that at 4–5 leaf stage spring oilseed rape seed yield could be theoretically calculated using these models: $y = –2.11 + 2.56\ln(13.538 + 0.00834t + 0.03609p + 0.00424r – 91.682n)$; $R^2 = 88.9\%$ or $y = –2.11 + 2.56\ln(3.7397 + 0.0009177t + 0.015835p + 0.004243r)$; $R^2 = 82.1\%$, where $170 \leq t \geq 270$ – GDD ≥ 5°C accumulated by plants from sowing till 4–5 leaf stage, $27 \leq p \geq 107$ – precipitation rate mm from sowing till 4–5 leaf stage, $0 \leq r \geq 240$ – nitrogen rate kg/ha applied at sowing and $0.130 \leq n \geq 0.150$ – total nitrogen content N% in 0–25 cm soil layer at sowing.

At the start of flowering spring oilseed rape seed yield could be predicted by these models: $y = 0.9 + 1.03\ln(–8.3836 + 0.006633t – 0.001546p + 0.006817r + 64.51779n$; $R^2 = 88.8\%$ or $y = 0.9 + 1.03\ln(2.25393 + 0.000616t + 0.004106p + 0.006817r)$; $R^2 = 81.7\%$, where $360 \leq t \geq 420$ – GDD ≥ 5°C accumulated by plants from sowing till the start of flowering, $48 \leq p \geq 135$ – precipitation rate mm from sowing till the start of flowering, $0 \leq r \geq 240$ – nitrogen rate kg/ha applied at sowing and $0.130 \leq n \geq 0.150$ – total nitrogen content N% in 0–25 cm soil layer at sowing.

Thus according to the data collected nitrogen concentration in spring oilseed rape plants during the vegetative growth season, mature seed and straw is related to the number of CD, GDD, MDT, PR, stand population density, nitrogen rate and application time, soil nitrogen content and the interaction among these factors. The experiment revealed the possibility for prognoses of spring oilseed rape and seed yield on the basis of collected data even at early plants growth stages.

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ABSTRAKT

Faktory ovlivňující koncentraci dusíku v jarní řepce (*Brassica napus* L.)

Vliv délky vegetační doby, průměrné denní teploty a srážek, počtu vegetačních dnů, dávky a termínu aplikace dusíku, hustoty porostu, obsahu půdního dusíku a vztah mezi uvedenými parametry a koncentrací dusíku v sušině rostlin jarní řepky během vegetační doby, ve zralých semenech a slámě byly sledovány v polním pětiletém pokusu u odrůdy Star. Nejvyšší obsah dusíku byl zjištěn u nejmladších rostlin. Prodloužení délky vegetační doby a zvýšené množství srážek mělo na koncentraci dusíku negativní vliv. Oproti tomu delší vegetační doba a vyšší průměrná denní teplota měly pozitivní vliv na obsah dusíku v semenech rostlin. Byla nalezena korelace mezi obsahem dusíku v jednotlivých růstových fázích a počasím, zatímco hustota rostlin na stanovišti koncentraci dusíku v rostlinách neovlivnila. Aplikace dusíku měla významný pozitivní vliv na růst obsahu dusíku v suché hmotě rostlin, v semenech i ve slámě. Při opožděné aplikaci dusíku se zvyšoval jeho obsah v biomase rostlin.

Klíčová slova: jarní řepka; obsah dusíku; dávka dusíku; termín aplikace; hustota rostlin na stanovišti; teplota; srážky; počet dnů růstu

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