Agronomy Research **1**(2), 229–243, 2003

Some factors affecting seed yield of spring oilseed rape (*Brassica napus* L.)

G. Sidlauskas[1] and S. Bernotas[2]

[1]Lithuanian Institute of Agriculture, Akademija 5051, Dotnuva parish, Kedainiai distr., Lithuania, e-mail: gvidas@lzi.lt
[2]Lithuanian Institute of Agriculture Vezaiciai branch, Vezaiciai, LT-5845 Klaipeda distr., Lithuania, e-mail: filialas@vezaiciai.lzi.lt

Abstract. The effect of nitrogen rates, time of nitrogen application, concentration of nitrogen, phosphorus and potassium in aboveground plant dry matter, stand population density, mean daily temperature, precipitation rate, growing degree days accumulated by plants at different growing stages and the duration of vegetative growth period on seed yield of Star, a cultivar of *Brassica napus* L., were studied in the field experiment. The seed yield was significantly affected by nitrogen rates of up to 120 kg ha^{-1}. Further increase in nitrogen fertilisation had only a little effect on the seed yield of spring oilseed rape. There was a possibility to prolong the nitrogen application time until the start of flowering. However, in poorest soils, especially under unfavourable growing and development conditions, late nitrogen application could be much less effective. Nitrogen concentration in plant dry matter at 4–5 leaf stage, at the start and end of flowering and at the seed development stage had a significant effect on seed yield of spring oilseed rape. Phosphorus concentration was not important in the second part of vegetative growth. Potassium concentration, on the contrary, in the first part. With an increase of stand population density to up to 170 plant m^{-2} seed yield of spring oilseed rape was increasing. The increase in the duration of vegetative growth period and precipitation rate resulted in a higher seed yield. Meanwhile, the increase of mean daily temperatures and growing degree days had a negative effect on seed yield of spring oilseed rape. Presented regression equations could be used for a model for prognosis of seed yield of spring oilseed rape, based on agronomic and climatic factors.

Key words: *Brassica napus* L., seed yield, nitrogen, NPK concentration, population density, temperature, precipitation, GDD

INTRODUCTION

Yield and its formation process depend on genetic, environmental and agronomic factors as well as the interaction between them. In recent years numerous attempts have been made to determine the optimum nitrogen fertiliser rate for spring oilseed rape (Geisler & Kullmann, 1991; Holmes, 1980; Sykes & Mailer, 1991). Almost all investigations show that nitrogen fertiliser causes a substantial yield increase in spite of diverse and contrasting growing conditions of oilseed rape. However, nitrogen requirement in the fertiliser can vary very much according to cultivars, soil type, climate and management (Grant & Bailey, 1993). Therefore it is very important to investigate and understand the influence of factors for the application of an appropriate amount of nitrogen fertiliser under the prevailing conditions. Moreover, the appropriate nitrogen fertiliser rate for oilseed rape is difficult to determine because of a poor relationship between nitrogen utilisation and seed yield (Merrien et al., 1991). Correct timing of nitrogen fertilizer application can also influence seed yield of spring oilseed rape. Optimum time of fertiliser application depends on the climate and soil indices. To prevent losses due to leaching, denitrification and immobilisation, or if a soil is very low in organic matter, generally nitrogen fertiliser should be applied close to seeding. However, in some conditions no significant difference was found between autumn and spring broadcast applications of nitrogen to oilseed rape (Nuttall et al., 1989). In subsequent studies, using four cultivars of oilseed rape, the yield was smaller with autumn-applied than with spring-applied nitrogen in two cultivars, and did not differ in two cultivars when a moderate level of nitrogen was applied (Nuttall & Malhi, 1991). When a high level of nitrogen was applied, there was no difference between application times for all tested cultivars. Nitrogen application at the rosette stage or during flowering may be too late and therefore less effective than application at the time of seeding (Helps, 1971; Nyborg, 1961; Perez & Mora, 1975).

Nitrogen content of oilseed rape plants, expressed as a percentage of the dry matter, is the highest at the rosette stage, falling steadily thereafter (Racz et al., 1965; Radet, 1955). The content of nitrogen of oilseed rape plants can vary over a wide range depending on growing conditions. There is very little known about the relationship between nitrogen content in plants at different growing stages and seed yield of spring oilseed rape grown in moderate climate. Therefore an attempt was made to assess the influence of nitrogen content in plants at different growing stages on seed yield of spring oilseed rape.

Crop yield can be affected by competitive stress among individual plants. Competition occurs when two or more plants need a particular factor necessary for growth, and when the immediate supply of this factor falls below the combined demands of the plants (Donald, 1963; Milthorpe & Moorby, 1974). In some trials spring oilseed rape generally shows slight and inconsistent seed yield responses to various seed rates (Christensen & Drabble, 1984; Helps, 1971; Kondra, 1977). In other studies seed yield decreased with decreased seeding rate (Bengtsson & Ohlsson, 1977; Clarke et al., 1978). Examination of yield elements has shown that rape seeds can compensate to a considerable degree for reduced plant density by increasing the numbers of lateral branches and pods per plant (Clarke et al., 1978; Clarke & Simpson, 1978).

There have been several studies of the effects of temperature and precipitation rate on growth and development of oilseed rape (Mendham et al., 1981; Morrison et al., 1989; Thurling & Vijendra Das, 1977). Plotting days to maturity against mean temperature gave nearly a linear relationship:

$$y = 185 - 7.8x; \qquad R^2 = 0.94 \tag{1}$$

indicating that each degree rise in temperature gave nearby 8 days earlier maturity (Mendham et al., 1981). It was found that in a cooler and longer season environment *Brassica napus* produced much higher yields as compared to plants grown under hot weather conditions (Rao & Mendham, 1991). It is clear that moderate temperatures and adequate water supply create better ripening conditions for seeds and allow them to expand to a bigger size with a higher oil content. However, there is a lack of information on the effect of temperatures and precipitation rate during different stages of development, the duration of growing stages as well as total vegetative growth period, and the interaction between these factors, on the final seed of yield spring oilseed rape.

The present study was planned to examine the effect of nitrogen rates and timing, nitrogen content in spring oilseed rape plants at different growing stages, stand population densities, mean daily temperatures, precipitation rate and length of different growing stages on mature seed yield of spring oilseed rape under moderate climate conditions. The relationships between climatic and agronomic factors and seed yield could be suitable for management, prediction and prognosis of spring oilseed rape yield.

MATERIALS AND METHODS

Spring oilseed rape cv. Star was grown on the Endocalcari-Epihypogleyic Cambisols soil of 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: organic matter - 1.8–2.1% (Tjurin procedure); N total - 0.132–0.181% (Kjeldahl technique after distillation); P_2O_5 - 180–220 mg kg^{-1} soil; K_2O - 170–210 mg kg^{-1} soil (AL-method); NO_3^- - N: 6.7–14.2 mg kg^{-1}; NH_4^+ - N: 2.5–3.8 mg kg^{-1}; N_{min} - 9.2–18.0 mg kg^{-1} (Bremner method); S total – 80–181 mg kg^{-1} (nephiliorimetricaly). The pH ranged from 6.4 to 7.2 when measured in 1 M KCl.

Spring oilseed rape was sown, according to meteorological conditions, between 28 April and 12 May in 1993–1997 with an interrow spacing of 12.5 cm. The experiment included three seeding rates of 4, 7, and 10 kg ha^{-1} (1,2, 2,1 and $3{,}0 \cdot 10^3$ ha^{-1}) seed. 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 single-doze applied nitrogen rates: 0, 60, 120, 180 and 240 kg ha^{-1}. Single-granular superphosphate (90 kg ha^{-1}) and potassium chloride (120 kg ha^{-1}) were broadcasted at drilling to maintain high nutrient levels in the soil and assure no negative effects on plant growth and yield formation process. Plots were arranged in a split-split – a plot with a completely randomised 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.

Weed control was provided by Fusilade super (fluazifop) applied to couch-grass (*Elytrigia repens* (L.) Nevski) at 3–5 leaf stage, Butisan S (metazachlor) applied during postemergence at 1–2 true leaf stage to control short-lived dicotyledonous and some monocotyledonous weeds, and Lontrel (clopyralid) applied if needed. Insect control, mostly for pollen beetle (*Meligethes aeneus*), was provided by Decis (deltamethrin) at the green bud stage.

After full germination, plants from an area of $1m^2$ of each plot were counted for determination of stand population density. The second count was made after harvesting the plots, counting left stubbles in an area unit. 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 concentrations in plant material were determined using Kjeldahl technique, phosphorus – colorimetrically and potassium – flame photometrically.

Plots were harvested in late August and 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. The baseline temperature used for growing degree days (GDD) computations was 5°C. Meteorological conditions varied widely between seasons. The spring of 1993 was warm and dry with heavy showers after sowing that caused a thick crust on the soil surface. The crust reduced emergence, and seedlings appeared 2 to 3 weeks late at the very end of May. The summer of 1993 was cool and extremely wet. Plant development was very slow and the trial was harvested at the end of September. The spring and summer of 1994 and 1995 were hot and extremely dry, especially the second parts of the vegetative season, and especially in 1994 when during one and a half month precipitation rate was only 0.3 mm and temperature higher than 30°C. The mean temperature in April and May in 1996 was higher compared to data of many years. June, and especially early July, were cool and wet. Starting from the mid-July and until spring oilseed rape harvest the weather was very hot and dry. The spring and early summer of 1997 were moderately cool and wet. The second part of the vegetative season was hot and dry with a mean daily temperature 1–3°C higher and 25–50% lower precipitation rate than weather records of many years.

An analysis of variance was used to test the 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 ** – $P \leq 0.01$. The statistical analysis was completed by using Statistica 5.5 version.

RESULTS AND DISCUSSION

Nitrogen rate. Oilseed crops require large amounts of nitrogen, as a component of plant proteins, amino acids, nucleotides, nucleic acids and chlorophyll. Oilseed crops yielding 2 t ha^{-1} contain about 124 kg ha^{-1} N in the aboveground portion (Ukrainetz et al., 1975). Spring oilseed rape accumulates 50–60 kg nitrogen for every ton of seed produced (Geisler & Kullmann, 1991; Grant & Bailey, 1993). Crop requirements in nitrogen are provided by the application of fertiliser and subsequent soil mineralisation. The coefficient of nitrogen usage from mineral fertilisers was low with winter oilseed rape, around 50% (Merrien et al., 1991). Optimum nitrogen dressing for oilseed crops varies more according to soil and climatic conditions, and lesser – according to cultivars. The summarised data show that in Europe spring oilseed rape responded well to a nitrogen amount between 120 and 200 kg ha^{-1} (Almond et al., 1986; Holmes, 1980). In Canada, requirements appeared to be more variable but were often in excess of 200 kg ha^{-1} of nitrogen (Holmes, 1980).

Data of a five-year study revealed that nitrogen fertilisers increased seed yield of spring oilseed rape from 24.4 to 64.0%. On average, seed yield of spring oilseed rape increased 0.43–0.70 t ha^{-1}, when nitrogen fertilisers were applied. Rates of nitrogen fertiliser also significantly affected the seed yield. On average, the biggest increase of spring oilseed rape seed yield, 0.44 t ha^{-1}, was noticed when 60 kg ha^{-1} nitrogen was applied. With application of 120 kg ha^{-1} nitrogen, seed yield increased up to 0.57 t ha^{-1} as compared to nitrogen non-treated plants. Further increase of nitrogen rate to 180 kg ha^{-1} did not affect the seed yield increase. When 240 kg ha^{-1} nitrogen was applied, seed yield of spring oilseed rape slightly increased up to 0.60 t ha^{-1}. The same tendencies were observed in each year of the experiment. Insignificant exception occurred in the extremely wet and cool weather, with a very long vegetative growth period, of 1993 and in the extremely hot and dry unusually short growth period of 1994. In the mentioned cases 180 kg ha^{-1} nitrogen rate slightly tended to increase seed yield of spring oilseed rape (0.04–0.08 t ha^{-1}) as compared to treatments with 120 kg ha^{-1} nitrogen applied.

Spring oilseed rape yield response to increasing rates of nitrogen fertiliser could best be expressed by a third-order polynomial distribution curve (Fig.1). This regression curve predicts a high yield at nitrogen fertilization rate of 120 kg ha^{-1}. At the same time, the third-order polynomial distribution curve indicates a possible higher yield at, or above, nitrogen rates of 240 kg ha^{-1}. Possibly the increase of nitrogen rates up to 240 kg ha^{-1}, or higher, can slightly influence a variety of canopy and yield structure parameters such as fertile pods per branch, or branches with fertile pods per plant, seed weight and number per pod, prolong the life of leaves, improve leaf area duration after flowering and increases overall crop assimilation, thus contributing to increased seed yield. However, the effects of extremely high nitrogen fertiliser rates on the maturity and quality of seeds as well as diseases and lodging must also be taken into account.

These findings correspond very well with the data collected in interior Alaska (Lewis and Knight, 1987). Rape seed yield of Candle, a cultivar of *Brassica campestris* L., as a function of nitrogen fertilisation rate, was explained by a third-order polynomial curve predicting a high seed yield at 105 kg ha^{-1} nitrogen rate and indicating a possible higher yield at a nitrogen rate of above 195 kg ha^{-1}:

$$y = 1.29 + 2.39\text{x}10^{-2}\text{N} - 1.96\text{x}10^{-4}\text{N}^2 + 5.23\text{x}10^{-7}\text{N}^3; \qquad R^2 = 0.43 \qquad (2)$$

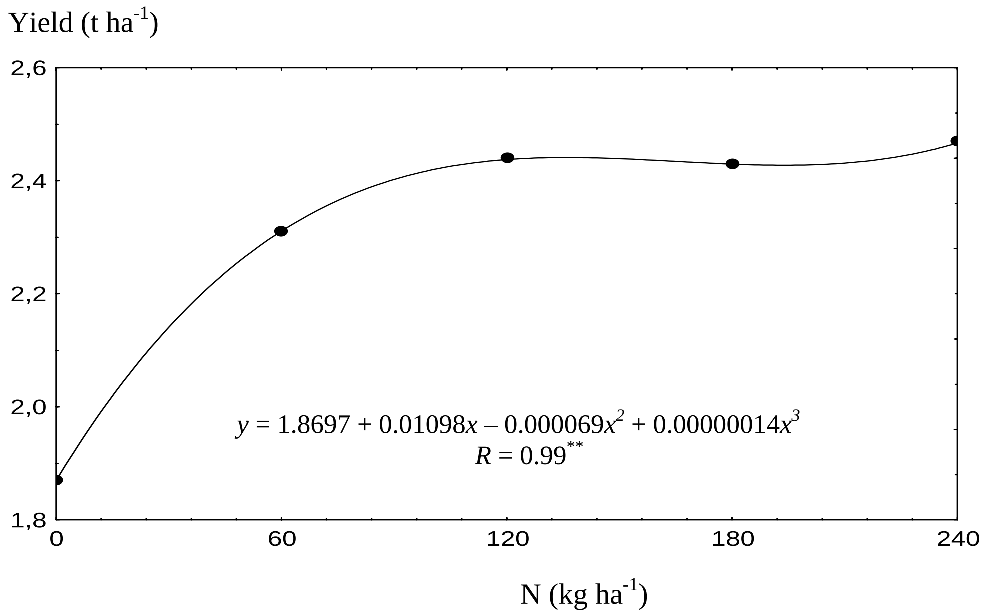

Fig. 1. Seed yield of spring oilseed rape as a function of nitrogen rate.

However, the relationship between nitrogen rates and seed yield in the mentioned study was not very strong indicating the effect of other factors or interaction between them on seed yield Thus under the tested conditions, seed yield of spring oilseed rape responded well to nitrogen fertilisation with an increase to up to 120 kg ha^{-1}. Nitrogen fertilisation above 120 kg ha^{-1} had little effect on seed yield. The interaction between seed yield of spring oilseed rape and increasing nitrogen fertilisation rates applied was very strong and reliable at P = 0.01 probability level.

Nitrogen application time. Optimum time of nitrogen fertiliser application mostly depends on climatic conditions, physical and chemical parameters of the soil, content of available nitrogen in the soil, plant development stage and interaction between these indices. Although in this study there was some variation in seed yield of spring oilseed rape from year to year, on average, there was a good response to the nitrogen application time. It was found that delayed nitrogen application time increased the average seed yield of spring oilseed rape in all treatments (seeding and nitrogen rate) for each nitrogen application time. When nitrogen was applied at sowing, 2.27 t ha^{-1} seed yield, on average, was obtained. With nitrogen application at 4–5 leaf stage, 2.30 t ha^{-1} seed yield was harvested. The highest seed yield of spring oilseed rape, 2.34 t ha^{-1}, matured in the treatments where ammonium nitrate was broadcasted at the start of flowering. However, in the cool and wet 1993 and extremely hot and dry 1994, the highest seed yield of spring oilseed rape was harvested when nitrogen fertilisers were applied at 4–5 leaf stage. Despite of that, in each year of the experiment, the lowest seed yield of spring oilseed rape matured in treatments with nitrogen application at sowing.

Delayed nitrogen application time, tended, on average, to increase seed yield of spring oilseed rape in each treatment of stand population density. In spite of plant density, the lowest yield was harvested when ammonium nitrate was broadcasted at sowing, the highest at the start of flowering. However, the differences in yield were small and, in some cases, not significant.

Interactions between nitrogen application time and nitrogen rates were significant for seed yield of spring oilseed rape, indicating that responses to different treatments were different. For example, seed yield of spring oilseed rape was increasing up to 120 kg ha^{-1} nitrogen rate, at 180 kg ha-^{1} nitrogen rate the yield was not increasing, but with 240 kg ha^{-1} nitrogen application seed yield tended to increase again when ammonium nitrate was broadcasted at sowing, or at the start of flowering. With nitrogen application at 4–5 leaf stage seed yield increased up to 120–180 kg ha^{-1} nitrogen rate and decreased significantly when 240 kg ha^{-1} nitrogen was applied.

A regression analysis revealed that the response of spring oilseed rape seed yield to nitrogen fertiliser rates applied at sowing, 4–5 leaf stage and at the start of flowering could be best expressed by second- and third-order polynomial curves (Fig. 2). The third-order curves fitted best for nitrogen application at sowing and at the start of flowering. For relationship between seed yield of spring oilseed rape and nitrogen rates applied at 4–5 leaf stage, the second-order polynomial curve was used. In all cases correlation between indices was very strong and reliable at P = 0.05 probability levels.

As for relationships when nitrogen was applied at sowing (R = 0.96*) and at the start of flowering (R = 0.96*), the second-order polynomial curves fitted well, and the $x_{\text{(N rate)ekstr.)}}$ were calculated. It was found that optimum nitrogen rates, when ammonium nitrate was applied at sowing and at the start of flowering, were 203.6 and 203.1 kg ha^{-1}, respectively. A further increase in nitrogen rate resulted in a seed yield decrease. However, when ammonium nitrogen was broadcasted at 4–5 leaf stage the optimum nitrogen rate was 161.2 kg ha^{-1}. The highest spring oilseed rape seed yield increase for 1 kg of nitrogen was achieved when ammonium nitrate was applied at the start of flowering at 60 kg ha^{-1} nitrogen rate.

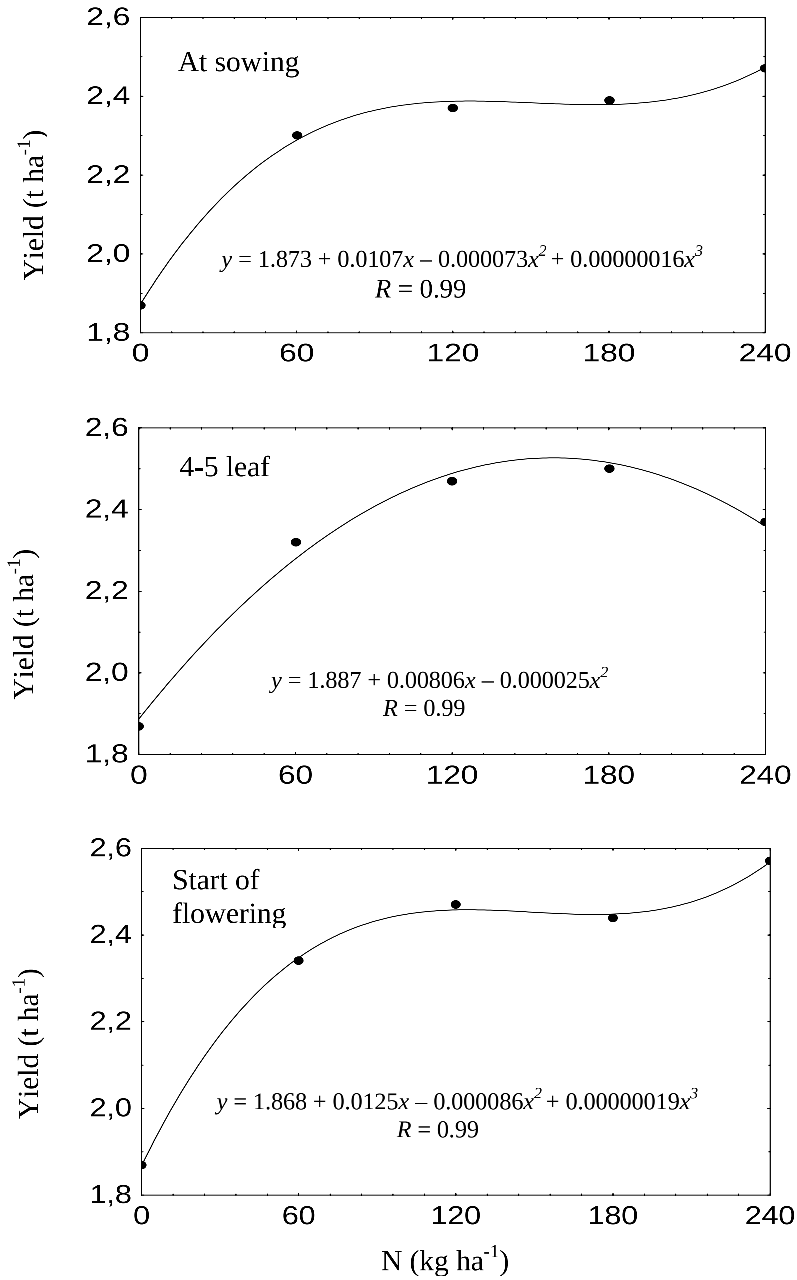

Fig. 2. Seed yield of spring oilseed rape as a function of nitrogen rate for each of three N application times.

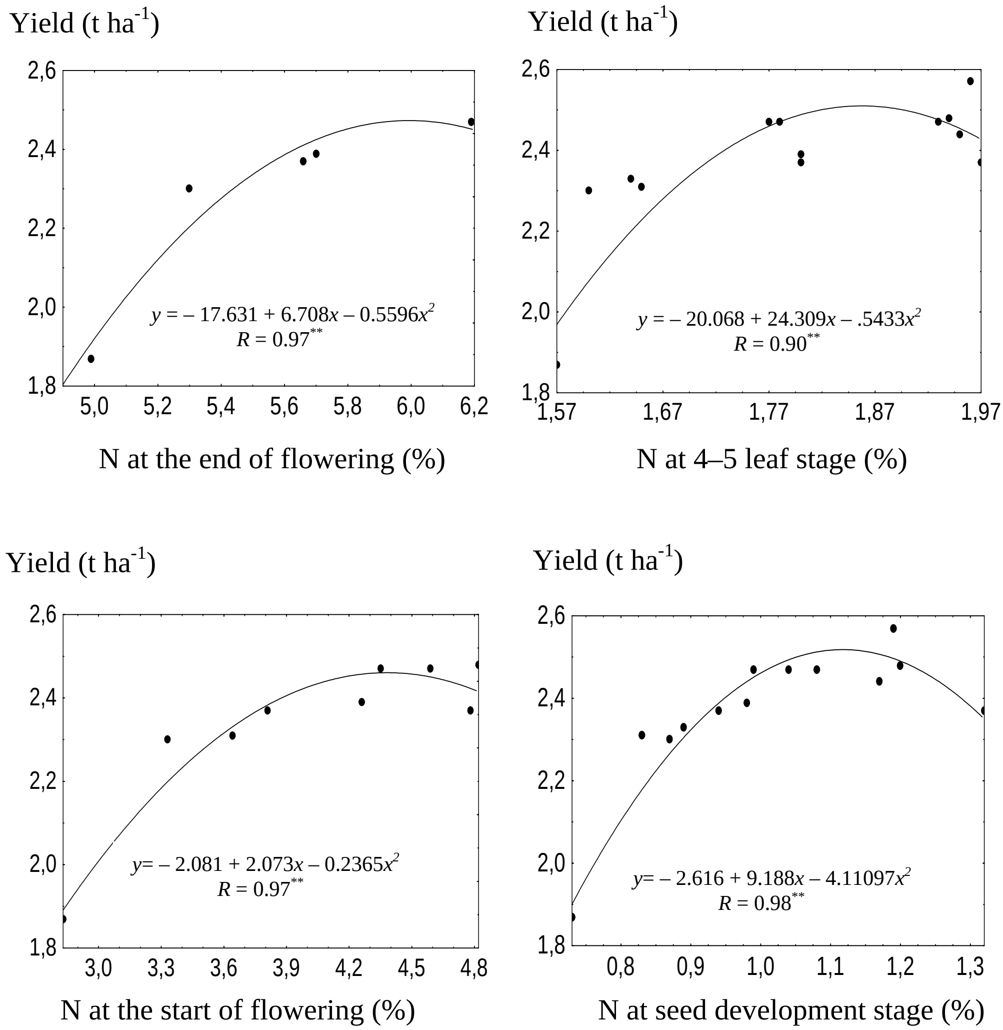

Fig. 3. Seed yield of spring oilseed rape as a function of plant nitrogen concentration at different growing stages.

Possibly in the soils with a high amount of organic matter, especially under favorable climatic conditions, nitrogen application time for spring oilseed rape can be delayed until the start of flowering. However, in poorest soils delayed nitrogen fertiliser application time could be much less effective.

Concentration of nitrogen, phosphorus and potassium. Nitrogen, phosphorus and potassium content expressed as a percentage of the dry matter is highest in young spring oilseed rape plants, when most of the dry matter is in the leaves and falls steadily with age (Holmes, 1980). In the experiment nutrient content in the dry matter of plants at various growth stages varied widely between years and seasons. On average, the highest nitrogen, phosphorus and potassium concentration of 5.57% N, 0.70% P and 5.50% K was determined at 4–5 leaf stage, decreasing at seed development stage to 1.02% N, 0.18% P and 1.89% K. The increase of nitrogen rates applied increased nitrogen concentration in spring oilseed rape plants. The changes in phosphorus concentration at various growth stages in relation to nitrogen rates applied were not regular and monosemantic. Potassium content in the dry matter of plants increased, or tended to increase, with the increase of nitrogen fertiliser rates.

There were found strong relationships between nitrogen concentrations in spring oilseed rape plants at 4–5 leaf stage, at the start and end of flowering, and at seed development stage and mature seed yield (Fig. 3).

Changes in the dry matter of spring oilseed rape plants at various growing stages significantly influenced seed yield of spring oilseed rape. For all tested growing stages the correlation between indices was very strong and reliable at $P = 01$ probability level. A correlation analysis using second-order polynomial curve revealed the maximum points of nitrogen concentration in the dry matter of spring oilseed rape at different growing stages, above which the seed yield increase ceased. This pattern was consistent from year to year and was not altered by stand population density and plant development stage. It was found that the maximum point of nitrogen concentration in plant aboveground dry matter ($x_{ekstr.}$) at 4–5 leaf stage was 5.99% N. Under the tested conditions, seed yield increase stopped above this point. The maximum point of nitrogen concentration at the start of flowering was found – 4.38% N. Earlier it has been reported that the required tissue level of nitrogen of the entire plant at flowering is between a range of 2.5–4.0% N and levels below 2.0% was considered deficient and levels above 5% N may be excessive (Grant & Bailey, 1993). With further growth, the nitrogen concentration in the aboveground dry matter of spring oilseed rape continued to decrease, and at the end of flowering the maximum point of nitrogen concentration was found to be 1.86% N and at the seed development stage – 1.12% N.

The analysis of collected data shows that the relationship between the phosphorus concentration in spring oilseed rape plants at 4–5 leaf stage and at the start of flowering and the seed yield of spring oilseed rape was poor and not significant. The increase of phosphorus concentration in the dry matter of plants at the end of flowering decreased seed yield of spring oilseed rape:

$$y = -3.28 - 5.12 \ln x; \qquad R = 0.65^{*} \tag{3}$$

However, the increase of phosphorus concentration in spring oilseed rape plants at the seed development stage showed a positive effect on mature seed yield:

$$y = 6.54 + 2.45 \ln x; \qquad R = 0.61^{*} \tag{4}$$

It is possible that such an effect of phosphorus concentration of aboveground dry matter in spring oilseed rape plants at different growth stages on spring oilseed rape seed yield may be caused by a high level phosphorus available for plants in the soil and by the growth and nutrition conditions.

Highly significant relationships between potassium content in spring oilseed rape plants at 4–5 leaf stage and at the start of flowering and mature seed yield was found. These interactions could be best expressed by logarithmic equations:

$$y = -4.08 + 3.73 \ln x_{(\text{K\% at 4–5 leaf stage})}; \qquad R = 0.98^{**} \tag{5}$$

$$y = -2.84 + 3.33 \ln x_{(\text{ K\% at the start of flowering})}; \qquad R = 0.95^{**} \tag{6}$$

However, in spite of that the increasing nitrogen rates increased the potassium content in the dry matter of spring oilseed rape also at the end of flowering and at the seed development stage, the relationships between potassium concentration and spring oilseed rape seed yield were poor and not significantly proved.

Thus the nitrogen concentration increase in the aboveground dry matter of spring oilseed rape plants at all tested growing stages increased mature seed yield. The effect of phosphorus concentration on seed yield of spring oilseed rape was noticed at the second part of the vegetative growth period of plants and was negative at the end of the flowering stage. At the seed development stage, the increase in phosphorus concentration showed a positive effect on mature seed yield. Potassium concentration in the dry matter of spring oilseed rape plants was more positively important at the first growing stages. At the second half of the growing season of spring oilseed rape, potassium concentration did not show any significant effect on mature seed yield.

Stand population density. Among the necessary factors for plant growth and development are water, nutrients, light, carbon dioxide, and oxygen. Plants can exhibit extreme plasticity by responding in size and form to the available space (Donald, 1963). Asymptotic and parabolic quantitative relationships between stand population density and crop yield was found (Holliday, 1960). According to asymptotic relationship the yield rises to a maximum with increasing plant density, but is relatively stable thereafter. This is usually encountered when the yield is a product of vegetative growth. A parabolic relationship occurs when certain plant population density gives maximum yield, declaiming above and below the optimum parameter. This type occurs when the yield is a product of reproductive growth.

In the experiment the relationship between spring oilseed rape plants number per m^2 and seed yield was asymptotic and for its expression quadratic equation fitted best (Fig. 4). The relationship between parameters was not strong but the coefficient of correlation was reliable at $P = 0.01$ probability level. A regression analysis revealed that the yield of spring oilseed rape was increasing with the increase of stand population density. The highest seed yield increase was noticed when plant density increased approximately up to 120 plants m^{-2}. After this point the effect of plant density on seed yield of spring oilseed rape was less obvious as the curve rose up slower. However, in the study the maximum point was not reached even at the highest tested stand population density 170 plant m^{-2}. The result corresponds with the recommended 100 plant m^{-2} plant density to achieve a high seed yield of spring oilseed rape (Ward et al., 1985). Obtained results also indicated that if the plants are uniformly distributed in the field, a reduction in plant density to about 50–60 plant m^{-2} would be acceptable. Therefore the flexibility in the seeding density of spring oilseed rape gives an opportunity to reduce input per area unit. This is of special importance in order to reduce the cost of producing and growing hybrid oilseed rape owing to its high prices compared with the traditional oilseed rape.

Climatic factors. Spring oilseed rape seed yield during the period of experiment varied widely because of annual fluctuations in weather, responded to applied nitrogen fertiliser and soil parameters. The shortest vegetative growth period, 101 calendar days, occurred in the hot and dry 1994. The longest – 124 calendar days – in the moderately cool and wet 1993. The highest seed yield of spring oilseed rape – 3.12 t ha^{-1} – was harvested in 1993. In 1994 matured the poorest seed yield, 1.49 t ha^{-1}. Precipitation rate during vegetative growth period varied widely from 127 to 419 mm. Mean daily temperatures fluctuated between 14.1 and 16.3°C and accumulated by plants growing degree days ≥ 5°C between 1106 and 1321°C.

A correlation analyses revealed that the seed yield of spring oilseed rape positively correlated to the number of calendar days after sowing and precipitation rate, and negatively to mean daily temperature and accumulation by plants of growing degree days during the vegetative growth period (Fig.5). In the field experiment conducted for 16-yr at different locations on black.

Melfort silty clay soil was found that an increase in mean maximum daily temperature from 21 to 24°C resulted in approximately 0.4 t ha^{-1} reduction in spring oilseed rape seed yield (Nuttall et al., 1992). The correlation between yield and precipitation rate for the months of July and August was positive. It was also found that mean maximum daily temperature and precipitation effects were greater with heavier nitrogen fertiliser rates. In our experiment the increase in nitrogen rates also increased the effect of the number of calendar days after sowing on seed yield of spring oilseed rape:

$y_{(N0)} = -16.67 + 3.84lnx$; $R = 0.59$ (7)

$y_{(N60)} = -25.9 + 6.001lnx$; $R = 0.78$ (8)

$y_{(N120)} = -29.22 + 6.73lnx$; $R = 0.82$ (9)

$y_{(N180)} = -27.90 + 6.45lnx$; $R = 0.87^*$ (10)

$y_{(N240)} = -28.51 + 6.58lnx$; $R = 0.88^*$ (11)

On average, the good response of spring oilseed rape seed yield to duration of vegetative growth period and nitrogen fertiliser application time was found. When the vegetative growth period was short, lasting up to 107 calendar days, the highest seed yield matured in treatments with nitrogen application at sowing:

$y = -22.53 + 5.29lnx$; $R = 0.84$ (12)

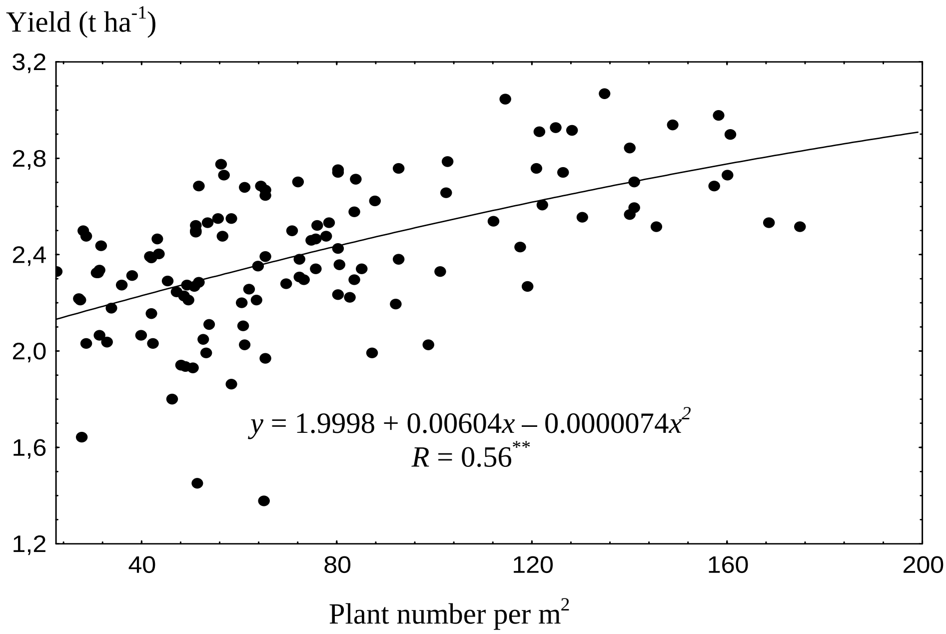

Fig. 4. The relationship between plant number and spring oilseed rape seed yield.

However, with the increase of vegetative growth period duration the highest seed yield was harvested when ammonium nitrate was broadcasted at 4–5 leaf stage or even later at the start of flowering. These relationships were expressed with logarithmic equations:

$$y_{(4\text{-}5\mathrm{leaf})} = -\,28.37 + 6.55 lnx; \quad R = 0.88^{*} \tag{13}$$
$$y_{(\mathrm{Start\ of\ flowering})} = -\,31.84 + 7.28 lnx; \quad R = 0.77 \tag{14}$$

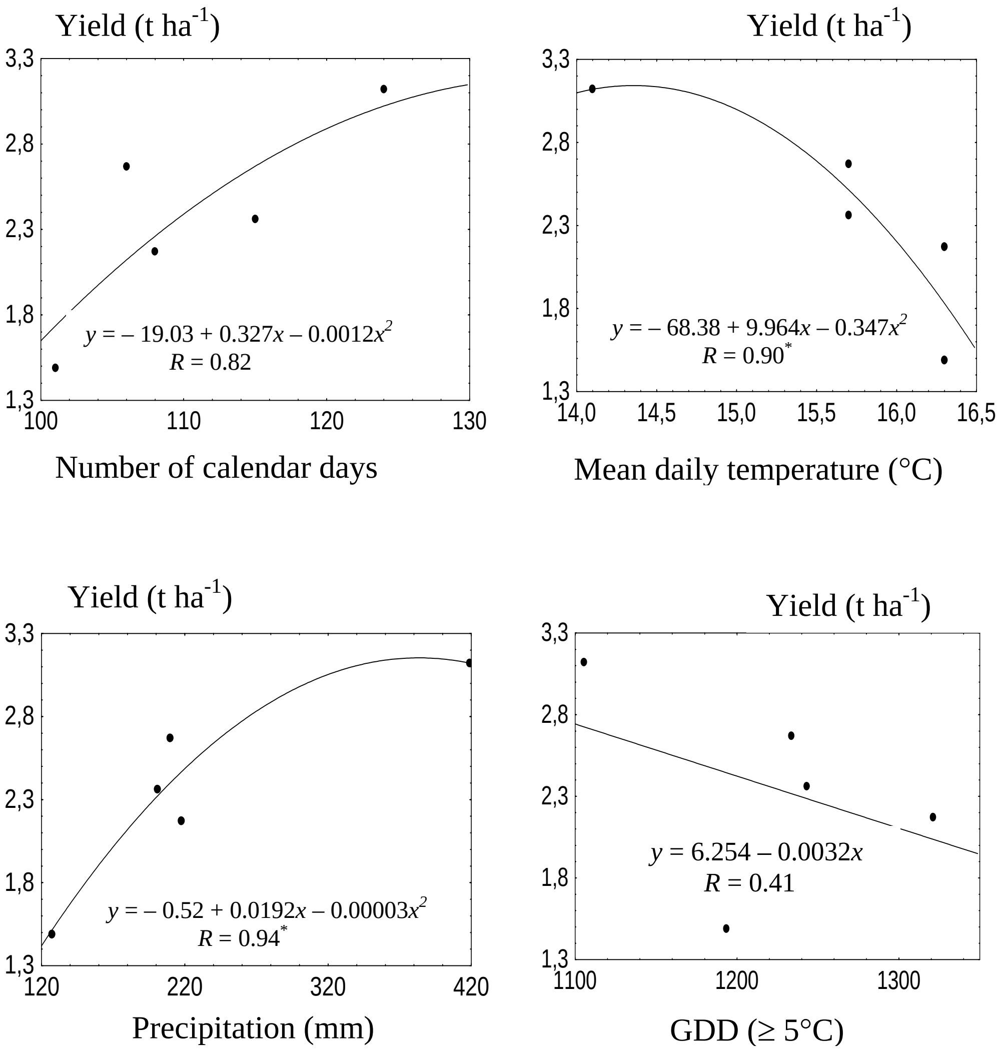

Fig. 5. Seed yield of spring oilseed rape as a function of number of calendar days, precipitation rate, mean daily temperature and GDD.

Table. Relationships between seed yield of spring oilseed rape (y t ha^{-1}) and precipitation rate (p mm) and GDD (t°C) accumulated by plants at different growing stages.

Growth stages	Regression equations	R^2
4 – 5 leaf	$y = -1.678 + 0.0077p + 0.0165t$	0.75
Start of flowering	$y = -2.918 - 0.0043p + 0.0154t$	0,70
End of flowering	$y = 4.485 + 0.0172p - 0.007t$	0.92*
Seed development	$y = 0.405 + 0.0054p + 0.0008t$	0.88*
Harvest	$y = -0.306 + 0.0055p + 0.0012t$	0.84*

Therefore the better effect of nitrogen fertiliser applied at sowing could be expected when the duration of the vegetative growth period of spring oilseed rape is short. The effect of delayed nitrogen application time could be more positive with the increasing of duration of the vegetative growth period of spring oilseed rape.

Seed yield of spring oilseed rape responded well to precipitation rate and growing degree days accumulated by plants at different growing stages. The relationships and multi-regression equations are presented in the Table.

Despite the fact that the interactions between indices at spring oilseed rape 4–5 leaf growing stage and at the start of flowering was not significantly proved at 05 probability level, presented equations allow use of the meteorological data for seed yield prognosis of spring oilseed rape even at early development stages of plants.

CONCLUSIONS

These experiments show that spring oilseed rape has a high demand for nitrogen fertilisers: up to 120 kg ha^{-1}. The further increase in nitrogen rate had little effect on spring oilseed rape seed yield. The interaction between the seed yield of spring oilseed rape and nitrogen fertilisation was expressed by the third-order polynomial distribution curve:

$$y = 1.8697 + 0.01098x - 0.000069x^2 + 0.00000014x^3; \quad R = 0.99^{**} \qquad (15)$$

In the soils with high a level of organic matter under favourable growth and development conditions, nitrogen fertiliser application time could be delayed until 4–5 leaf stage, or even until the start of flowering. However, in poorest soils delayed nitrogen application time, especially until the start of flowering, could be less effective, or even risky.

Increasing of nitrogen fertiliser rates increased nitrogen concentration in spring oilseed rape plants during the vegetative growth period. Nitrogen concentration at 4–5 leaf stage, at the start and end of flowering and at the seed development stage had a strong effect on seed yield of spring oilseed rape. The relationships between the indices were significant and could be used for a yield prediction model. Phosphorus concentration effect on spring oilseed rape seed yield was most important at the end of flowering and seed development stages. Potassium concentration in spring oilseed rape plant dry matter showed the highest effect on seed yield at 4–5 leaf stage and at the start of flowering.

Increasing stand population density also affected positively seed yield of spring oilseed rape. However, at the highest tested 170 plant m^{-2} stand population density the maximum seed yield increase was not reached. Calculations based on a quadratic response curve showed that the yield of seeds under the tested conditions would be increasing up to 400 plant m^{-2}.

Seed yield of spring oilseed rape correlated well with the duration of vegetative growth period, precipitation rate and mean daily temperature. The relationship between yield and growing degree days accumulated by plants was weak and insignificant. It was found that with the increase of nitrogen fertiliser rates applied, the effect of weather indices on seed yield of spring oilseed rape also increased. Presented relationships could be used for a prognosis model of seed yield of spring oilseed rape based on nitrogen rate and timing, nutrient concentration in the plants aboveground dry matter at different growing stages, stand population density and weather records.

ACKNOWLEDGEMENTS**.** The authors wish to express their thanks to S.H. "Norman" Chien from International Fertiliser Development Center for the advices and revision of the manuscript.

REFERENCES

Almond, J.A., Dawkins, T.C.K.& Askew, M.F. 1986. Aspects of crop husbandry. In: *Oilseed rape*. (Scarisbrick, D.H, Daniels, R.W., eds.), pp.127–176. Collins,

Bengtsson, A.& Ohlsson, I. 1977. Row spacing in oilseed crops. *Proceedings of the 4th International Rape seed Conference*. Giessen, West Germany, June 4–8, pp. 207–215.

Christensen, J.V. & Drabble, L.C. 1984. Effect of row spacing and seeding rate on rapeseed yield in northwest Alberta. *Can. J. Plant Sci.,* **64**, 1011–1014.

Clarke, J.M., Clarke, F.R.& Simpson, G.M. 1978. Effect of method and rate of seeding on yield of *Brassica napus. Can. J. Plant Sci.,* **58**, 549–550.

Clarke, J.M. & Simpson, G.M. 1978. Influence of irrigation and seeding rates on yield and yield components of *Brassica napus* cv. Tower. *Can. J. Plant Sci.,* **58**, 731–737.

Donald, C.M. 1963. Competition among crop and pasture plants. *Adv. Agron*., **159**, 1–118.

Geisler, G. & Kullmann, A. 1991. Changes of dry matter, nitrogen content and nitrogen efficiency in oilseed rape in relation to nitrogen nutrition. *Proceedings of the 8th International Rapeseed Congress,* 1175–1180. Saskatoon, Canada.

Grant, C.A. & Bailey, L.D. 1993. Fertility management in canola production. *Can. J. Plant Sci.,* **73**, 651–670.

Helps, M.B. 1971. Methods of sowing, seed rate and nitrogen level for oilseed rape. *Exp. Husbandry,* **20**, 69–72.

Holliday, R. 1960. Plant population and crop yield. *Nature,* **186**, 22–24.

Holmes, M.R.J. 1980. Nutrition of the oilseed rape crop. *Applied Science Publishers Ltd*.

Kondra, Z.P. 1977. Effect of planted seed size and seeding rate on rapeseed. *Can. J. Plant Sci.,* **57**, 277–280.

Lewis, C.E. & Knight, C.W. 1987. Yield response of rapeseed to row spacing and rates of seeding and N – fertilization in interior Alaska. *Can. J. Plant Sci.,* **67**, 53–57.

Mendham, N.J., Shipway, P.A. & Scott R.K. 1981. The effect of delayed sowing and weather on growth, development and yield of winter oil-seed rape (*Brassica napus*). *J. Agric. Sci. Camb.,* **96**, 389–416.

Merrien, A., Champolivier, L., Devineau, J., Estragnat & A., Jung, L. 1991.Volarisation de l'azote par une culture de colza d'hiver. *Proceedings of the 8th International Rapeseed Congress*, 1186–1192. Saskatoon, Canada.

Milthorpe, F.L. & Moorby, J. 1974. An introduction to crop physiology, 1st Edition. Cambridge University Press, London.

Morrison, M.J., McVetty, P.B.E. & Shaykewich, C.F. 1989. The determination and verification of a basaline temperature for the growth of Westar summer rape. *Can. J. Plant Sci.,* **69**, 455–464.

Nuttall, W.F., Dawley, W.K., Malhi, S.S. & Bowren, K.E. 1989. The effect of spring and fall application of N on yield and quality of barley (*Hordeum vulgare* L.) and rapeseed (*Brassica campestris* L.). *Can. J. Plant Sci.*, **69**, 199–211.

Nuttall, W.F. & Malhi, S.S. 1991. The effect of time and rate of N application on the yield and N uptake of wheat, barley, flax and four cultivars of rapeseed. *Can. J. Plant Sci.*, **71**, 227–238.

Nuttall, W.F., Moulin, A.P. & Townley–Smith, L.J. 1992. Yield response of canola to nitrogen, phosphorus, precipitation and temperature. *Agron. J.*, **84**, 765–768.

Nyborg, M. 1961. The effect of fertilizers on emergence of cereal grains, flax and rape. *Can. J. Plant Sci.*, **41**, 88–98.

Perez, G. & Mora, S. 1975. Dates and rates of application of different nitrogen fertilizers on spring oilseed rape. *Agro Sur.*, **3**, 98–108.

Racz, G.J., Webber, M.D., Sopper, R.J. & Hedlin, R.A. 1965. Phosphorus and nitrogen utilization by rape, flax and wheat. *Agron. J.*, **57**, 335–337.

Radet, E. 1955. Fertilizing winter rape in Champagne. *Annals Agronomiques, Serie A.*, 922–935.

Rao, M.S.S. & Mendham, N.J. 1991. Comparison of Chinoli (*Brassica campestris* subsp. *oleifera* x subsp. *chinensis*) and *B. napus* oilseed rape using different growth regulators, plant population densities and irrigation treatments. *J. Agric. Sci. Camb.,* **117**, 177–187.

Sykes, J.D. & Mailer, R.J. 1991. The effect of nitrogen on yield and quality of canola. *Proceedings of the 8th International Rapeseed Congress,* 554–557. Saskatoon, Canada.

Thurling, N. & Vijendra Das, L.D. 1977. Variation in the pre-anthesis development of spring rape (*Brassica napus* L.). *Aust. J. Agric. Res.*, **28**, 597–607.

Ukrainetz, H., Sopper, R.J. & Nyborg, M. 1975. Plant nutrient requirements of oilseed and pulse crops. In *Oilseed and pulse crops in Western Canada*. (Harapiak, J.T., ed.), pp. 325–374. Western Cooperative Fertilizers Ltd., Calgary, AB.

Ward, J.T., Basford, W.D. & Hawkins, J.H. 1985. Oilseed rape. *Farming Press*, Suffolk.