RESEARCH

CHILEANJAR
CHILEAN JOURNAL of AGRICULTURAL RESEARCH

EFFECTS OF SOURCE AND RATE OF NITROGEN FERTILIZER ON YIELD, YIELD COMPONENTS AND QUALITY OF WINTER RAPESEED (*Brassica napus* L.)

Özden Öztürk[1]

ABSTRACT

Winter rapeseed (*Brassica napus* L.) has potential to become an alternate oilseed crop both for edible oil production and energy agriculture (biofuel production) for Turkey. This study was conducted to determine the effect of year, N sources and doses on the yield and quality traits of winter rapeseed in a cereal system in calcareous soils over two seasons, 2000-2001 and 2001-2002, in Central Anatolia. Three N sources, ammonium sulfate, ammonium nitrate and urea, were applied as hand broadcast on the soil surface at five doses (0, 50, 100, 150, and 200 kg N ha^{-1}). The traits investigated were plant height, number of branches and pods per plant, number of seed per pod, thousand seed weight, seed yield, oil and protein content. There were significantly effects on seed yield, oil and protein content, and other yield components due to N sources and rates. In general, ammonium sulfate and urea gave higher seed yield than ammonium nitrate. Mean values of both seasons indicated that 100 and 150 kg N ha^{-1} rate increased significantly yield and quality traits with regard to other N treatments. The present results highlight the practical importance of adequate N fertilization and true N source in seed yield in winter rapeseed and suggest that ammonium sulfate at 150 kg N ha^{-1} will be about adequate to meet crop N requirements.

Key words: winter rapeseed, seed yield, oil content, protein content, *Brassica napus*.

INTRODUCTION

Winter rapeseed (*Brassica napus* L.) is an important agricultural crop, grown commonly for oil or biofuel production. After oil extraction, the high protein seed residue can be used as animal feed. Winter rapeseed is mainly cultivated in Europe, Asia, North America and Australia, but has a limited acreage in Turkey. Presently, over 50% of vegetable oil consumed in Turkey is imported from abroad. Rapeseed production has potential as an alternative income source for the Turkey producer. Although its production is still limited, this crop has large expansion possibilities. It is an alternative principally in areas where wheat (*Triticum aestivum* L.) is the only winter crop or in marginal areas for this cereal.

In Turkey, 75% of the arable land is devoted to cereals, of which 67% is occupied by wheat. Drought stress is also a serious abiotic stress factor limiting crop production in Turkey, especially in Central Anatolia, which covers nearly 45% (4.5 million ha) of the Turkish wheat-producing area. It is semiarid and the driest region in the country, where the soil is also generally poor in plant-available N concentration. Winter rapeseed is a new and promising oilseed crop for many region of Turkey such as Central Anatolia. In Turkey, winter rapeseed is usually cultivated in a crop rotation including winter wheat and winter barley (*Hordeum vulgare* L.).

For newly introduced crops, it is necessary to assess the appropriate production technology for different environments. Amongst many others, the nutritional requirements of the crop are considered to be the most important factor. Nitrogen fertilizer plays a vital role in enhancing crop yield (Rathke *et al*., 2005). Compared to cereals, winter rapeseed requires a higher amount of nutrients, and available N frequently limits seed yield. Hocking *et al*. (1997) said that rapeseed requires about 25% more N than wheat.

Yield response of rapeseed to increasing N doses varies with different environmental variables, including weather, soil type, residual fertility (especially nitrate), soil water content, and cultivar. Many studies have shown that both growth and yield of rapeseed are enhanced significantly by high doses of applied N (Bilsborrow *et al*., 1993; Kumar *et al*., 2001; Cheema *et al*., 2001). Nitrogen increases yield by influencing a number of growth parameters

[1]University of Selcuk, Faculty of Agriculture, Konya, Turkey.
*Corresponding author (ozdenoz@selcuk.edu.tr; ozdengulsum@gmail.com).
Received: 04 November 2008.
Accepted: 03 April 2009.

such as number of branches and pods per plant, seeds per pod and 1000 seed weight by producing more vigorous growth and development (Taylor *et al*., 1991; Qayyum *et al*., 1998). Rapeseed needs to accumulate between 200 and 250 kg N ha^{-1} to yield 2500 kg seed ha^{-1} (Grant and Bailey, 1993). In Argentina it has been reported that seed yield increases with 150 kg N ha^{-1} (Sarandon *et al*., 1996). Sheppards and Bates (1980) noted increased yield with increasing N rates up-to 100 kg ha^{-1}. Ibrahim *et al*. (1989) concluded that yield increased with rates of N up-to 213 kg ha^{-1}. Excess N, however, can reduce seed yield and quality appreciably (Cheema *et al*., 2001; Laaniste *et al*., 2004). An excessive N rate or an inadequate moment of N application could increase N content in seeds, decreasing oil content and their commercial value (Chamorro *et al*., 2002). Besides, excessive application of fertilizers affects negatively the farmer economy and environment.

Choosing the correct dose, source and timing of N fertilizer application is therefore an important aspect of successful rapeseed production. The problem of type of applied fertilizers, rarely taken into consideration by researches and in practice, is even more ambiguous (Wiesler *et al*., 1999). In spite of the well-recognized effects of the main N fertilizer components, i.e. N sources and/or some other nutrients as a secondary components on soil and plants, the third N factor, i.e. chemical composition of the applied N fertilizers, is seldom treated as an important factor in the rapeseed production system (Wiesler *et al*., 1999).

Previous study (Öztürk and Akınerdem, 2000) revealed that rapeseed yielded satisfactory and could be grown successfully as winter crop under Central Anatolia conditions. However, there are no published research data on the N rate and sources for winter rapeseed. The objective of this study was evaluate the impact of applying different N rate and sources on rapeseed yield and oil content, results that are critical to promoting winter rapeseed cultivation.

MATERIAL AND METHODS

The research was carried out in the Agricultural Experiment and Research Centre, Faculty of Agriculture, University of Selçuk, Konya, Central Anatolia region (37º35' N, 32º47' E, 1013 m.a.s.l.), Turkey, during the growing seasons 2000-2001 (Y1) and 2001-2002 (Y2). Soil samples (0-30 cm) were taken at sowing and analyzed for some parameters. The experimental soil was a clay loam with 0.94% organic matter content and pH of 7.8. Total N content was 0.03%, available P was 3.26 mg kg^{-1}, available K was 78.0 mg kg^{-1}, $S0_4$-N was 3.0 mg kg^{-1} and no salinity problems were observed (Table 1). Organic matter was determined by the Modified Walkley-Black procedure; $CaCO_3$ was determined by Sheibler's Calcimeter method (Black, 1965); available P was measured by Olsen method according to Black (1965); available K was measured by flame photometry (Knudsen *et al*., 1982); total N was determined by the Kjeldahl method (Bremner, 1965) and sulfate-S was determined by ICP-AES (Varian Vista Model) following extraction by 0.2 N KH_2PO_4 according to the Soltanpour and Workman (1981).

The average and minimum temperatures, monthly rainfall and relative air humidity data for Y1, Y2 and long term mean (1939-2000) during the rapeseed vegetation period (September-July) are shown in Table 2. In both years, mean temperature was close to the 62 yr average value. There was considerable variability in rainfall amounts and distribution from year to year. The amount of rainfall and average relative air humidity were more suitable for plant growth in Y2 than in Y1. Rainfall received during the vegetation period (September-July) in Y1 was 191.2 mm, which was less than long-term average (321.6 mm) and had an erratic distribution. In early spring (March-April) there was a dry period. In Y2 more rain was received, 375.4 mm in total. The mean Y1 relative air humidity (57.1%) was below to long term mean (60.0%), whereas Y2 relative air humidity (66.0%) was above.

Sowing was done with hand during the 3rd week of September in both years. The previous crop was winter wheat for each year. The variety used in the experiment was 'Honk', a winter type rapeseed variety. Cultivar selection was based on yield performance from earlier trials (Öztürk and Akınerdem, 2000).

The study used a split plot design, with N fertilizer source (ammonium nitrate [AN], ammonium sulfate [AS], and urea) as the main plot and N rate as the subplot. Nitrogen treatments were 0, 50, 100, 150, and 200 kg N ha^{-1} (N_{0-200}). The experiment was replicated three times. Plots were overseeded and subsequently thinned to final plant density of about 50 plants m^{-2} at seedling stage. The

Table 1. Soil properties of the experimental site at 0-30 cm depth.

Properties	Value
Soil texture	Clay-loam
Organic matter, %	0.94
$CaCO_3$, %	38.00
Total N, %	0.03
Available phosphorus, mg kg^{-1}	3.26
Available potassium, mg kg^{-1}	78.00
Sulfate-S, mg kg^{-1}	3.00
pH	7.80
Electrical conductivity, dS m^{-1}	0.19

Table 2. Weather conditions during the two test growing season and long-term (62-yr) mean (LTM) for winter rapeseed in Konya, Turkey.

	Rainfall			Temperature			Relative air humidity		
	LTM	Y1	Y2	LTM	Y1	Y2	LTM	Y1	Y2
	mm			ºC			%		
September	11.4	4.5	6.2	18.2	19.0	19.8	48.0	42.6	46.5
October	29.3	32.3	1.9	12.3	11.2	12.8	60.0	60.0	60.0
November	31.4	26.2	57.1	6.4	6.9	6.0	72.0	60.5	78.5
December	40.8	22.1	114.6	1.8	1.4	2.5	79.0	79.1	85.0
January	39.3	2.8	22.4	-0.2	2.1	-6.7	78.0	78.5	86.6
February	31.4	8.0	13.6	1.5	2.2	2.7	74.0	67.5	74.6
March	29.8	6.6	33.4	5.4	10.7	7.9	65.0	53.9	61.0
April	31.0	14.4	50.4	11.1	11.8	9.7	58.0	53.0	73.6
May	45.5	72.8	35.4	15.8	14.7	14.9	56.0	60.8	60.8
June	25.0	0.2	7.4	19.9	21.5	19.8	50.0	37.4	51.4
July	6.5	1.3	33.0	23.2	26.3	23.3	42.0	35.2	48.6
Annual mean	321.4	191.4	375.4	10.5	11.6	10.2	62.0	57.1	66.0

Y1: growing season 2000-2001; Y2: growing season 2001-2002.

area of each plot was 9.6 m^2 consisting of eight rows, 4 m long and 30 cm apart. A 1.0-m alley was left around each plot to avoid plot to plot N contamination. Nitrogen was applied as split in two applications; half was drilled into the soil before sowing and the remaining half was topdressed at the flower-bud-visibility stage (BBCH51; Biologische Bundesanstalt Bundessortenamt and Chemical Industry-BBCH scale; Meier, 2001). All plots received P at 80 kg ha^{-1} as triple superphosphate before sowing in both seasons.

Weeds were controlled by hand as needed. Plots were irrigated once at sowing to allow an immediate and homogeneous emergence during both growing seasons. Plots were sprayed with malathion before flowering to protect against a beetle (*Omophlus caucasicus*) and aphids.

Treatments were hand-harvested at technological maturity stage (BBCH89) at the beginning of July each year. Seed yields were taken at maturity by harvesting the center six rows of each plot for seed yield determination. Subsamples were dried at 105 ºC for moisture determination. Seed yield was adjusted to 9% moisture content (Bilsborrow *et al*., 1993), and all other measurements were reported on a dry weight basis. Twenty plants were randomly collected from the central six rows and the following growth and yield component variables were recorded for each plot; plant height, primary branches per plant, pod number per plant and 1000 seed weight. The number of seeds per pod was determined on a random subsample of 20 pods. Seed oil content was determined, after drying at 70 ºC for 48 h (Billsborrow *et al*., 1993), by Soxhlet extraction technique, using diethyl ether, as reported by AOAC methods 920.39 (AOAC, 1980), and seed N concentration by the Kjeldahl procedure, AOAC method 920; N was multiplied by 6.25 to convert to protein content (Rathke *et al*., 2005). Statistical analysis was conducted using the MSTAT-C statistical package (Crop and Soil Department, Michigan State University, Michigan, USA). Analysis of variance (ANOVA) was performed on experimental data obtained from a randomized complete block in a split plot arrangement. The *F* test was then applied to examine the statistical significance of differences among treatments. All statistically significant main effects and interactions were considered. Differences among treatments were tested by ANOVA and compared using Least Significant Difference (LSD) test at 0.01 and 0.05 levels of significance.

RESULTS AND DISCUSSION

Year (Y) x N source (F) x N rate interaction was observed for any yield or agronomic traits, except 1000 seed weight. F x N rate interaction was significant for plant height, number of branch number and pods per plant and seed yield (Table 3). Y x F and Y x N rate interactions usually were insignificant for yield and other agronomic traits, except seed protein content.

Yield components

Plant height was affected by Y, F, N rate and F x N rate interaction (Table 3). The highest plant height (126.8 cm) was obtained in Y2 (Table 4). This result could be explained by differences in the weather conditions especially total rainfall amount and distribution between years.

Table 3. Analysis of variance for yield, yield components and quality of winter rapeseed.

Source of variation	Df	Plant height	Branch number	Pod number	Seed number	Thousand seed weight	Seed yield	Seed oil content	Seed protein content
		cm	—— n^o plant^{-1} ——		n^o pod^{-1}	g	kg ha^{-1}	——— % ———	
Year (Y)	1	*	**	ns	ns	**	ns	*	*
N source (F)	2	**	**	ns	*	ns	*	**	*
Y x F	2	ns	ns	ns	ns	ns	ns	ns	**
N rate	4	**	ns	**	ns	*	**	**	**
Y x N rate	4	ns	ns	ns	ns	ns	ns	ns	**
F x N rate	8	**	*	*	ns	ns	**	ns	ns
Y x F x N rate	8	ns	ns	ns	ns	*	ns	ns	ns

*p < 0.05; **p < 0.01; Df: degrees of freedom; ns: non significant.

All the N fertilizer treatments significantly increased plant height compared with control. Maximum plant height (131.0 cm) was observed with 150 kg N ha^{-1}, but thereafter, at the highest N rate (N$_{200}$) it decreased significantly (Table 4). This result agrees with that of Özer (2003).

In this research, AN and urea produced significantly taller plants than AS. Nitrogen sources responded differently to increasing N rates for plant height. This caused significant F x N rate interaction (Table 3). The F x N rate interaction indicated that the maximum plant height (138.5 cm) was observed in plots treated with AN at 150 kg N ha^{-1} (Figure 1a).

Year affected branch number significantly (Table 3). Branch number was on average 8.7 in the Y2 and 7.7 in the Y1 (Table 4). This shows that differences in weather conditions over years may affect branch number significantly.

In this research, increasing N rates usually caused increases in branch number of rapeseed plants (Table 4), as has been previously reported (Özer, 2003), but it was not significant. By the other hand, effects of N sources and F x N rate interaction on the branch number per plant were significant (Table 3).

In this research, the highest branch number per plant (8.5) was obtained with AN and the lowest (7.7) with AS (Table 4). The highest branch number (9.1) was obtained with N$_{200}$ application of AN (Figure 1b). The increase in number of branches per plant with increase in N rate may

Table 4. Influence of nitrogen sources and nitrogen rate on yield and some agronomic characters of winter rapeseed grown in Central Anatolia, Turkey.

Treatments	Plant height	Branch number	Pod number	Seed number	Thousand seed weight	Seed yield	Seed oil content	Seed protein content
	cm	—— n^o plant^{-1} ——		n^o pod^{-1}	g	kg ha^{-1}	——— % ———	
Year (Y)								
2000-2001	122.7b*	7.7b**	228.6	28.7	3.4b**	2530	42.83b*	23.75a
2001-2002	126.8a	8.7a	252.6	28.3	4.6a	2944	44.33a	21.43b*
N source (F)								
Ammonium sulfate	121.5b**	7.7b**	236.8	28.9a*	4.0	2819a*	44.32a**	22.17b*
Ammonium nitrate	126.5a	8.5a	256.1	27.8b	4.1	2624b	42.56b	22.76a
Urea	126.2a	8.3ab	228.9	28.8a	3.9	2766ab	43.85a	22.82a
N rate (N)								
0	117.5c**	7.9	195.8c**	27.7	3.7c*	2147d**	39.17d**	20.36c**
50	123.5b	8.1	262.8ab	29.4	4.0b	2757bc	42.47c	22.85b
100	128.0ab	8.1	239.1abc	28.7	4.1ab	3016ab	46.23a	22.83b
150	131.0a	8.7	283.4a	28.4	4.3a	3165a	44.97b	23.89a
200	124.0b	8.3	221.9bc	28.3	4.0b	2598c	45.03b	23.00ab
CV, %	4.22	11.73	24.39	6.08	11.07	11.37	2.55	4.73

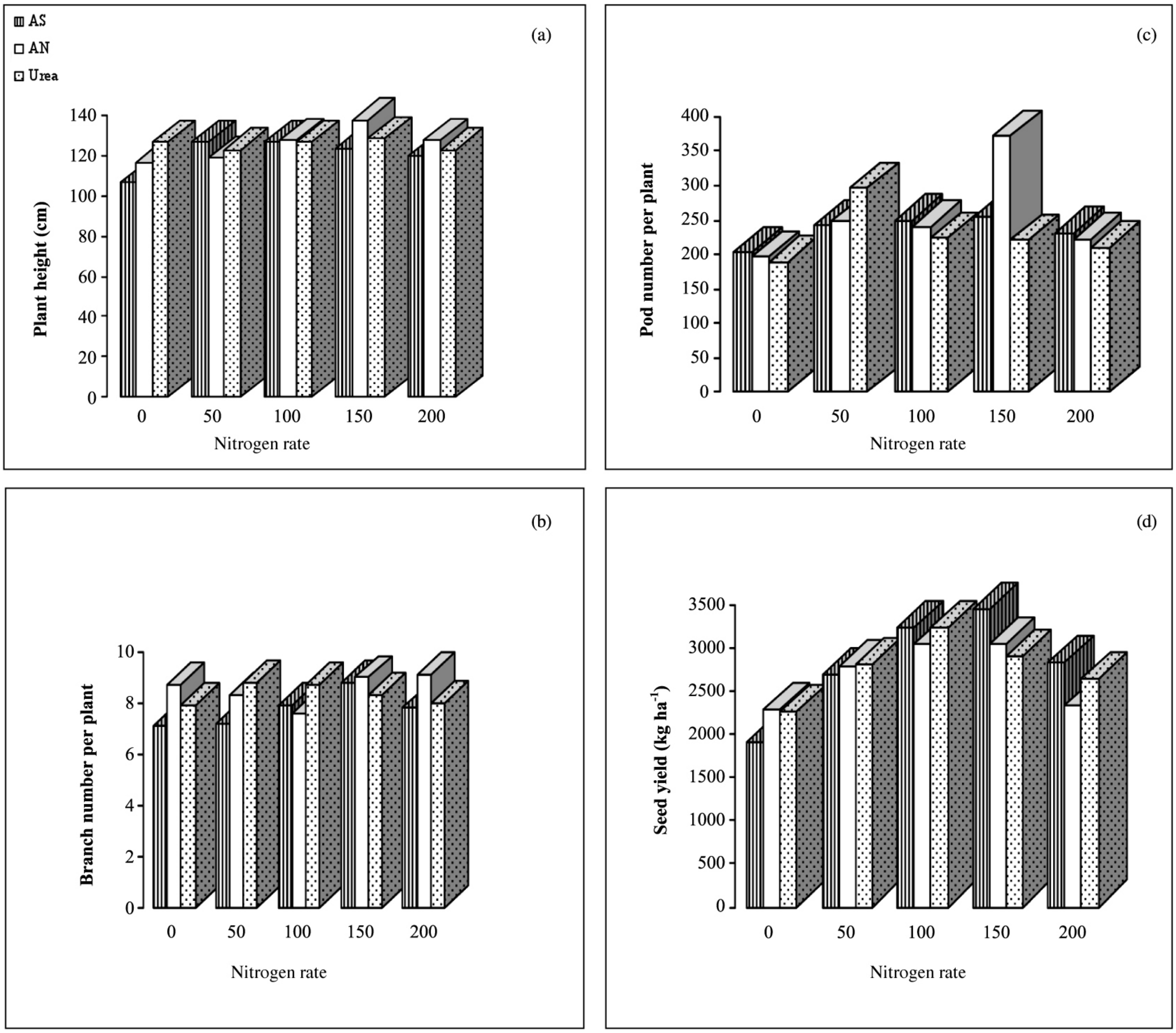
*Values within columns with the same letter are not significant at P < 0.05; **P < 0.01 according to Least Significant Difference (LSD) test. CV: coefficient of variation.

be due to the fact that N promoted vegetative growth and branching on the inflorescence. These results agree with those documented by Uddin *et al*. (1992), who stated that number of branches per plant significantly increased with N doses from 0 to 150 kg ha^{-1}.

There was no effect of Y and F on pod number per plant. However, N rate and F x N rate affected the pod number (Table 3). The number of pods per plant increased with increasing N rates up-to N_{150}. Thereafter, it declined slightly at the highest fertilizer rate (N_{200}). Data showed that maximum pods per plant (283.4) were recorded in those plots which received 150 kg N ha^{-1} while the minimum (195.8) was produced by control plots (Table 4). These results agree with findings by Qayyum *et al*. (1998), Cheema *et al*. (2001) and Khan *et al*. (2002). The N rates effects for pod number were inconsistent for N sources, leading to significant F x N rate interaction (Table 3). The highest pod number per plant (372.1) was found with 150 kg N ha^{-1} application of AN while the lowest pod number per plant (188.9) was obtained with control application of urea (Figure 1c).

Number of seeds per pod was affected by F (Table 3). Maximum of 28.9 seeds per pod were recorded in AS, however, it did not differ from urea (28.8, Table 4). The N dose was not different (Table 3); however, it increased with increase in N rate from 0 to 50 kg ha^{-1}, and decreased beyond this level (Table 4). These results are different from Quayyum *et al*. (1998), who stated that increasing N rate from 0 to 120 kg ha^{-1} significantly increased the number of seeds per pod.

Thousand seed weight (TSW) was affected by Y, N rate and Y x F x N rate interaction (Table 3). In Y1,



AN: ammonium nitrate; AS: ammonium sulfate

Figure 1. Influence of nitrogen source and nitrogen rate (kg N ha^{-1}) on plant height (a), branch number per plant (b), pod number per plant (c) and seed yield (d) of winter rapeseed.

rapeseed had a lower TSW than Y2 (Table 4). This shows that the differences in weather conditions over years may affect TSW significantly. TSW decreases as a result of poor seed filling in years without enough rain and water in the soil. This was the case in the first year of experiment. Similar results have been reported by Özer (2003).

A steady and progressive increase in TSW was observed with each increment in applied N rates up-to 150 kg ha^{-1}, the best result was at N_{150} with 4.3 g (Table 4). These results are in line with those reported by Uddin *et al*. (1992), who observed that TSW increased significantly when N was increased from 0-150 kg ha^{-1}.

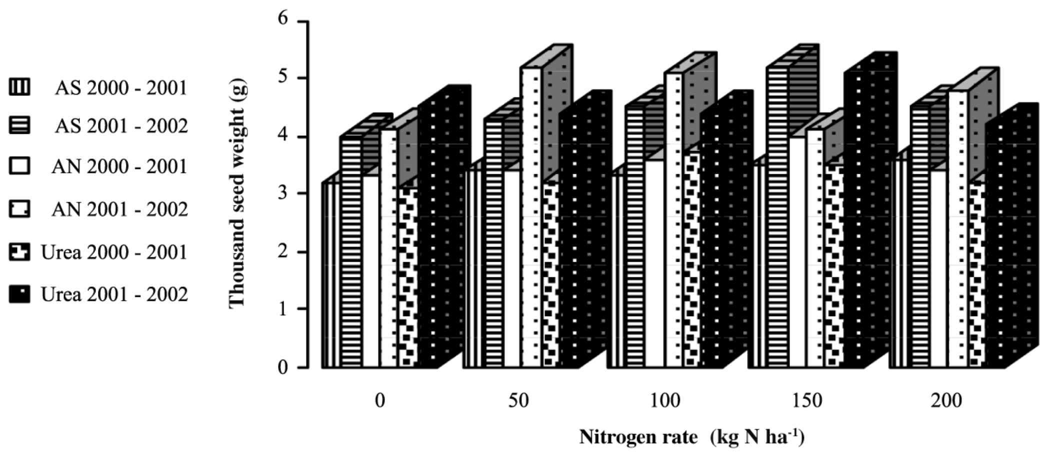
When the Y x F x N rate was divided into components: the highest TSW (5.2 g) was obtained with Y2 x AS x N_{150} and Y2 x AN x N_{50} combinations, and the lowest TSW (3.1 g) was obtained with Y1 x urea x N_0 treatment, whereas Y1 x AS x N_0, Y1 x urea x N_{50} and Y1 x urea x N_{200} did not differ significantly (Figure 2).

Seed yield

Seed yield was affected by F, N rate and F x N rate interaction (Table 3). Seed yield increased significantly with increase in N rate up-to 150 kg ha^{-1}. Maximum seed yield (3165 kg ha^{-1}) was obtained by plots that received 150 kg N ha^{-1}, while minimum seed yield (2147 kg ha^{-1}) was obtained by control plots. Seed yield increased significantly by 47.41% with increasing N application from 0 to 150 kg ha^{-1} and, thereafter, decreased significantly by 21.82% from 150 to 200 kg ha^{-1} (Table 4).

The positive yield response of rapeseed to higher N rates was not surprising. As previously explained, winter rapeseed has a high N requirement (Grant and Bailey, 1993; Rathke *et al.,* 2005). The positive impact of N on the seed yield of winter rapeseed has been reported by Cheema *et al*. (2001) and Rathke *et al*. (2005). According to Rathore and Manohar (1989) and Jan *et al*. (2002), seed yield of winter rapeseed increased significantly when N was increased from 0 to 220 kg N ha^{-1} depending on site conditions. Maximum yield at higher N levels than control might be due to the fact that all yield components, i.e., number of branches per plant, number of pods per plant, number of seeds per pod and 1000 seed weight, increased with increase in N. These results agree with those reported by Cheema *et al*. (2001) and Khan *et al*. (2002). In this study, the fact that the soil of the experimental field is low in N (0.03%) can be seen as an important factor for the reaction of rapeseed to N fertilizer. When soil N content is inadequate, N addition increases significantly seed yield in rapeseed (Christensen *et al*., 1985). Nevertheless, some authors noted a stagnation or even reduction in seed yield at high rates of N fertilizer (Hocking *et al*., 1997; Cheema *et al*., 2001).

Ammonium sulfate had higher seed yield (2819 kg ha^{-1}) than other N sources (Table 4). AS fertilizer, which is physiologically acidic, is more efficient than AN -just as in research field soils- especially in alkaline environments where lime content is high. Since AS decreases pH, it leads to the dissolution of many micro elements and thus makes them available for the plant (Kacar and Katkat, 2007). AS contains S different from the other N sources. Sulfur is probably the most important soil fertility factor to consider when growing rapeseed (Franzen, 1997). Sulfur requirements for rapeseed are higher than most crops (Fismes *et al*., 2000). Rapeseed takes up sulfate-S. The source of S fertilizer may be ammonium sulfate (21-0-0-24S) or another available fertilizer containing sulfate. In this trial, sulfate content of research soils was low (3 mg kg^{-1}). Based on this result, it was estimated that the



AN: ammonium nitrate; AS: ammonium sulfate

Figure 2. Year x Nitrogen source x Nitrogen rate interaction for thousand seed weight.

positive effect of AS on seed yield of rapeseed comparing the other N sources in this study may be associated with S content in AS. Investigations in the North East of Scotland, where soil S content is low, appropriate S application to rapeseed resulted in quadrupling yield (Walker and Booth, 1992). Similar results were obtained in field experiments of Rathore and Manohar (1989), Fismes *et al*. (2000) and Khan *et al*. (2002).

Seed yield increased in response to each increment of added N, but decreased with additional N from 100 to 150 kg ha^{-1} in AS while decreased from 150 to 200 kg ha^{-1} in other sources (Table 4), which caused significant F x N rate interaction for seed yield (Table 3). The highest seed yield was obtained with AS x N_{150} (3435 kg ha^{-1}) and the lowest yield with AS x N_0 (1901 kg ha^{-1}; Figure 1d). Yield increased in a quadratic way for N sources (Figure 3). Regressions between AS, AN, and urea and N application rates were significant (P < 0.01). High R^2 in N sources (R^2 = 0.76 for AN, R^2 = 0.97 for AS, and R^2 = 0.86 for urea) indicates a close relationship between seed yield and N rates. Jackson (2000) has reported similar results.

Success or failure in the use of N fertilizers depends as much on climate conditions, variety and application method as on the features of the soil. Turkey's annually average rainfall is 643 mm, but in Konya region is 322 mm. Both annual rainfalls in Konya are lower than Turkey's average and distribution changes year to year. From total rainfall, 57% correspond to autumn and winter. Winter precipitation is commonly snow and covers whole field and plants. In this research, the amount and distribution of rainfall was more suitable for rapeseed in Y2 than in Y1 (Table 2). Especially, April rainfall, when the second half of N was applied, in Y1 was considerably lower (14.4 mm) than in Y2 (50.4 mm). A disadvantage of spring topdressing N on winter rapeseed is that rainfall is required to move N into the root zone before it is available to the rapeseed plant. If spring season is very dry, N fertilizer on the soil surface may not be available to the rapeseed, and some N may be lost to the air through volatilization. Bayrakli *et al*. (1995) reported N losses from the soils with lower water content when N is applied in spring. Late N applications in spring or a long drought period after N application may not be useful for the plants, whereas rainfall and increases in temperatures after the N application increase seed yield.

Oil content

Year, F and N rate affected oil content significantly (Table 3). In the first year of the study, the determined oil content was 42.8% and in the second year increased to 44.3% (Table 4). Climatic conditions could be considered as a determining factor for oil production. In Y1, the reduction in oil content was thought to be result of unsuitable weather conditions. It is likely that increased temperature and water stress during seed filling was a major cause of reduced oil concentration. Similar results have been reported by Hocking and Stapper (2001) and Özer (2003).

Effects of N sources on the oil content of rapeseed were significant (Table 3). Oil content obtained from AS fertilization (44.32%) was higher than that of the other N sources and can be attributed to 24% S content, because S plays an important role in the chemical composition of seed and increases the percentage of oil content of seed (Khan *et al*., 2002). In general, N fertilization without S reduced total oil production due to the decrease in yield (Joshi *et al*., 1998). Besides, water shortage occurring during flowering or pod-filling stages may favor increased protein content and thereby decreasing oil content (Bouchereau *et al*., 1996).

Oil content increased in a quadratic way in N sources (Figure 4). High R^2 in N sources (R^2 = 0.94 for AN, R^2 = 0.88 for AS, and R^2 = 0.96 for urea) indicates a close relationship between oil content and N rates. Different N rates significantly affected percentage seed oil content (Table 4). Seed oil content varied from 39.17% (N_0) to 46.23% (N_{100}). The data showed that seed oil content

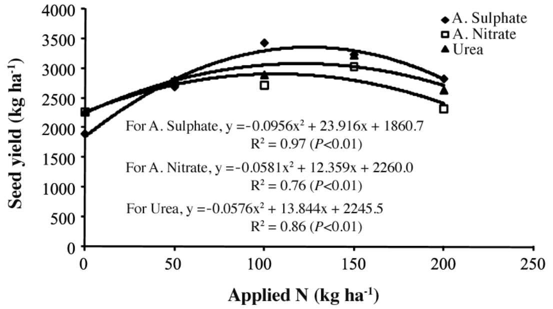


Figure 3. Seed yield as a function applied in winter rapeseed in different nitrogen sources.

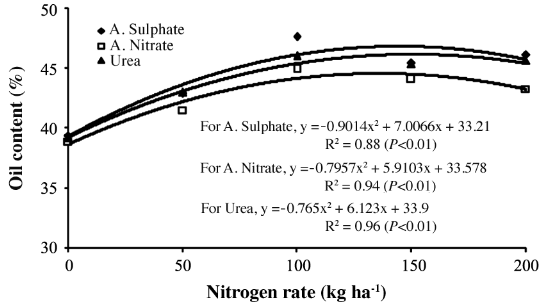


Figure 4. Oil content as a function applied in winter rapeseed in different nitrogen sources.

increased 18.02% with increasing N application from 0 to 100 kg ha^{-1} and then it decreased significantly. The possible reason for the decrease in oil content with N increase may be due to the fact that N is the major constituent of protein so it might increase the percentage of seed protein, as a result there might be decrease in the percentage of oil content since it has inverse relationship with protein. The results agree with those documented by Jan *et al*. (2002) and Özer (2003).

Protein content

Seed protein content was affected by Y, F and N rate (Table 3). Mean comparison of the 2 yr data revealed that higher protein contents were recorded in Y2 (Table 4), and can be attributed to plant stress in March-April 2001 when the rainfall and relative humidity were low (6.6 and 14.4 mm, and 53.9 and 53.0%, respectively; Table 1), decreasing seed yield and increasing seed protein content. Fowler *et al*. (1990) reported a negative correlation between soil water content and seed protein content at all development stages. Besides, water shortage occurring during flowering in Y1 (Table 2) may favor decreased oil content and thereby increasing protein content.

Rapeseed is not only an oilseed crop, but also contains a relatively high seed protein concentration (> 400 g kg^{-1} oil-free meal) and its meal is used as a protein supplement for animals and possibly will be for humans in the near future. Because of its high protein content, rapeseed and other *Brassica* species in general require sufficient N during their growth for protein synthesis (Wang *et al*., 2008). In this research, the maximum seed protein concentration (23.89%) was achieved at N_{150} rate, which showed a 17.34% increase over the control (Table 4). Ogunlela *et al*. (1990) reported that N concentrations in rapeseed seeds increased with increasing N rates. These results are consistent with those reported by Bilsborrow *et al*. (1993) and Özer (2003).

There was no difference in seed protein content over years and N rates with urea (22.82%) and AN (22.76%) (Tables 3 and 4). Protein content increased in a quadratic way for N sources (Figure 5). High R^2 in N sources (R^2 = 0.91 for AN, R^2 = 0.86 for AS, and R^2 = 0.90 for urea) indicates a close relationship between seed yield and N rates. Seed protein content generally increased with increasing N rate, with concomitant decrease in oil content (Asare and Scarisbrick, 1995). Strong negative correlation between oil and protein content in seeds was reported by several authors (Taylor *et al*., 1991; Cordeiro *et al*., 1993; Chamorro *et al*., 2002). Y x F and Y x N rate interactions were significant (Table 3), which means that the effects of fertilizer N sources and doses on the seed protein content differed over years.

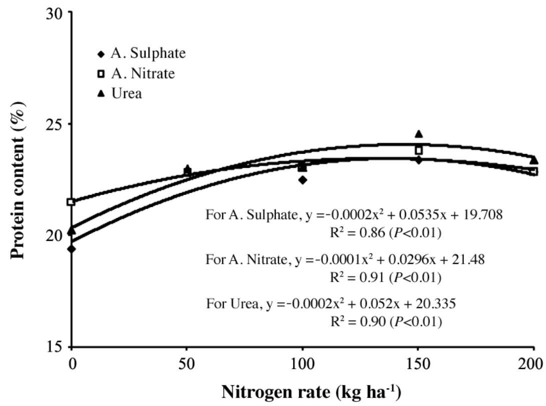


Figure 5. Protein content as a function applied in winter rapeseed in different nitrogen sources.

CONCLUSIONS

The soils of Central Anatolia are generally alkaline, have low organic matter content and available N, but have high lime content. Because of that, N source is important for rapeseed production. According to our study, yield and quality of winter rapeseed was influenced by N fertilizer sources and doses. As the mean of 2 yr, 150 kg N ha^{-1} rate was optimum and ammonium sulfate was suitable N source for winter rapeseed on calcareous soils in Anatolia. Maximum seed yields were obtained with ammonium sulfate at 150 kg N ha^{-1}, while minimum seed yield was produced by control plots, which clearly suggest the importance of N sources and doses for higher seed production in rapeseed crops. However, significant yield increases were observed only up to 150 kg N ha^{-1} in all N sources. The results of the present study may be helpful for the recommendation of optimum N source and rate in winter rapeseed production in similar climatic and soil conditions.

RESUMEN

Efecto de la fuente y dosis de fertilizantes nitrogenados en el rendimiento, componentes de rendimiento y calidad de semilla de canola (*Brassica napus* L.) El raps (*Brassica napus* L.) tiene potencial para convertirse en un cultivo oleaginoso alternativo para producción de aceite comestible y agricultura energética (producción de biodiesel) en Turquía. Este estudio fue conducido para determinar el efecto del año, fuente y dosis de N en las características de rendimiento y calidad de raps en un sistema cerealero en suelos calcáreos en dos temporadas, 2000-2001 y 2001-2002, en Anatolia Central. Se aplicaron al voleo tres fuentes de N (sulfato de amonio, nitrato de amonio y urea) en cinco dosis (0, 50, 100, 150 y 200 kg N ha^{-1}). Las características investigadas fueron altura de planta, número de ramas y vainas por planta, número de semillas por vaina, peso de mil semillas, producción de semilla, y contenido de aceite y proteína. Hubo efectos significativos de fuente y dosis de N en producción de semilla, contenido de aceite y proteína, y otros componentes del rendimiento. En general, sulfato de amonio y urea produjeron mayor producción de semilla que nitrato de amonio. Los valores medios de ambas temporadas indicaron que dosis de 100 y 150 kg N ha^{-1} aumentaron significativamente las características de rendimiento y calidad. Estos resultados destacan la importancia práctica del uso de fuente y dosis de N adecuadas en la producción de semilla en raps, y sugieren que el sulfato de amonio a 150 kg N ha^{-1} suplirá los requerimientos de N del cultivo.

Palabras clave: raps, producción de semilla, contenido de aceite, contenido de proteína, *Brassica napus*.

LITERATURE CITED

AOAC. 1980. Official methods of analysis. 13th ed. p. 7021-7024. Association of Analytical Chemists, Gaithersburg, Maryland, USA.

Asare, E., and D.H. Scarisbrick. 1995. Rate of nitrogen and sulphur fertilizers on yield, yield components and seed quality of oilseed rape (*Brassica napus*). Field Crops Res. 44:41-46.

Bayrakli, F., S. Gezgin, H. Polat, Ş. Uyanöz, H.Özaytekin, and M. Zengin. 1995. Azotlu gübrelerden amonyak gazı uçması şeklinde cereyan eden azot kayıplarının belirlenmesi ve bu kayıpların önlenmesi için alınması gereken tedbirler üzerine bir araştırma. Selçuk Üniv. Ziraat Fak. Konya. TÜBİTAK. TOAG-899 nolu proje raporu.

Bremner, J.M. 1965. Total nitrogen. Methods of soil analysis: Chemical and microbiological properties. Part II. p. 1238-1255. *In* Black, C.A. (ed.) American Society of Agronomy, Madison, Wisconsin, USA.

Bilsborrow, P.E., E.J. Evans, and F.J. Zhao. 1993. The influence of spring nitrogen on yield, yield components and glucosinolate content of autumn sown oilseed rape. J. Agric. Sci. (Cambridge) 120:219-224.

Black, C.A. 1965. Methods of soil analysis. Agronomy Nº 9. Part 2. American Society of Agronomy, Madison, Wisconsin, USA.

Bouchereau, A., N. Clossais-Besnard, A. Bensaoud, L. Leport, and M. Renard. 1996. Water stress effects on rapeseed quality. Eur. J. Agron. 5:19-30.

Chamorro, A.M., L.N. Tamagno, R. Bezus, and S.J. Sarandon. 2002. Nitrogen accumulation, partition, and nitrogen-use efficiency in canola under different nitrogen availabilities. Commun. Soil Sci. Plant Anal. 33:493-504.

Cheema, M.A., M.A. Malik, A. Hussain, S.H. Shah, and S.M.A. Basra. 2001. Effects of time and rate of nitrogen and phosphorus application on the growht and seed and oil yields of canola (*Brassica napus* L.) J. Agron. Crop Sci. 186:103-110.

Christensen, J.V., W.G. Legge, R.M. De Pauw, A.M.F. Hennig, J.S. McKenze, B. Siemens, and J.B. Thomas. 1985. Effect of seeding date, nitrogen and phosphate fertilizer on growth, yield and quality of rapeseed in Nortwest Alberta. Can. J. Plant Sci. 65:275-284.

Cordeiro, D.S., E.P. Sılveira, e A.N. Kichel. 1993. Resposta da *Brassica napus* a rates e epocas de aplicaçao de nitrogenio. Pesq. Agropec. Bras. 28:1137-1142.

Fismes, J., P.C. Vong, A. Guckert, and E. Frossard. 2000. Influence of sulphur on apparent N-use efficiency, yield and quality of oilseed rape (*Brassica napus* L.) grown on a calcareous soil. Eur. J. Agron. 12:127-141.

Fowler, D.B., J. Brydon, B.A. Darroch, M.H. Entz, and A.M. Johnston. 1990. Environment and genotype influence on grain protein concentration of wheat and rye. Agron. J. 82:655-664.

Franzen, D.W. 1997. Fertilizing mustard and canola. Bull. SF-1122. North Dakota State Univ. Ext. Service, Fargo, North Dakota, USA.

Grant, C.A., and L.D. Bailey. 1993. Fertility management in canola production. Can. J. Plant Sci. 73:651-670.

Hocking, P.J., P.J. Randall, and D. Demarco. 1997. The response of dryland canola to nitrogen fertilizer: Partitioning and mobilization of dry matter and nitrogen, and nitrogen effects on yield components. Field Crops Res. 54:201-220.

Hocking, P.J., and M. Stapper. 2001. Effect of sowing time and nitrogen fertilizer on canola and wheat, and nitrogen fertilizer on Indian mustard. I. Dry matter production, grain yield, and yield components. Aust. J. Agric. Res. 52:623-634.

Ibrahim, A.F., E.O. Abusteit, and El-M.A. El-Metwally. 1989. Response of rapeseed (*Brassica napus* L.) growth, yield, oil content and its fatty acids to nitrogen rates and application times. J. Agron. Crop Sci. 162: 107-112.

Jackson, G.D. 2000. Effects of N and S on canola yield and nutrient uptake. Agron. J. 92:644-649.

Jan, A., N. Khan, I.A. Khan, and B. Khattak. 2002. Chemical composition of canola as affected by nitrogen and sulphur. Asian J. Plant Sci. 1:519-521.

Joshi, N.I., P.C. Mali, and A. Saxena. 1998. Effect of nitrogen and sulphur application on yield and fatty acid composition of mustard (*Brassica juncea* L.) oil. Agron. Crop Sci. 180:59-63.

Kacar, B., and V. Katkat. 2007. Gübreler ve Gübreleme. 2. Baskı. Nobel Yayın N° 1119. Fen ve Biyoloji Yayınları Dizisi: 34, Ankara. 559 s.

Khan, N., A. Jan, I. Ihsanullah, A. Khan, and N. Khan. 2002. Response of canola to nitrogen and sulphur nutrition. Asian J. Plant Sci. 1:516-518.

Knudsen, D.G., A. Peterson, and P.F. Pratt. 1982. Lithium, sodium and potassium. p. 247-262. *In* Page, A.L. (ed.) Methods soil analysis. Part 2. Agronomy Monograph 9. ASA and SSSA, Madison, Wisconsin, USA.

Kumar, A., D.P. Singh, S. Bikram, and Y. Yashpal. 2001. Effects of nitrogen application and partitioning of biomass, seed yield and harvest index in contrasting genotype of oilseed brassicas. Ind. J. Agron. 46:528-532.

Laaniste, P., J. Jaudu, and V. Eremeev. 2004. Oil content of spring oilseed rapeseeds according to fertilization. Agron. Res. 2:83-86.

Meier, U. 2001. Growth stages of mono- and dicotyledonous plants. 2nd ed. Federal Biological Research Centre for Agriculture and Forestry, Berlin, Germany.

Ogunlela, V.B., A. Kullmann, and G. Geisler. 1990. Nitrogen distribution and dry matter accumulation in oilseed rape (*Brassica napus* L.) as influenced by nitrogen supply. J. Agron. Crop Sci. 164:321-333.

Özer, H. 2003. Sowing date and nitrogen rate effects on growth, yield and yield components of two summer rapeseed cultivars. Eur. J. Agron. 19:453-463.

Öztürk, Ö., and F. Akınerdem. 2000. Bazı kışlık kolza çeşitlerinde farklı ekim zamanı ve sıra arası uygulamalarının verim ve kalite üzerine etkisi. Selçuk Üniv. Ziraat Fakültesi Dergisi 14:93-110.

Qayyum, S.M., A.A. Kakar, and M.A. Naz. 1998. Influence of nitrogen levels on the growth and yield of rape (*Brassica napus* L.) Sarhad J. Agric. 15:263-268.

Rathke, G.W., O. Christen, and W. Diepenbrock. 2005. Effects of nitrogen source and rate on productivity and quality of winter oilseed rape (*Brassica napus* L.) grown in different crop rotations. Field Crops Res. 94:103-113.

Rathore, P.S., and S.S. Manohar. 1989. Response of mustard to nitrogen and sulphur. Indian J. Agron. 34:336-338.

Sarandon, S.J., A.M. Chamorro, L.N. Tamagno, y R. Bezus. 1996. Respuesta de la colza-canola (*Brassica napus* L. ssp. *oleifera forma annua*) a la fertilización con N a la siembra. Efecto sobre la acumulación y partición de la materia seca, el rendimiento y sus componentes. Rev. Fac. Agron. (La Plata) 101:179-186.

Sheppards, S.C., and T.E. Bates. 1980. Yield and chemical composition of rape in response to nitrogen, phosphorus and potassium. Can. J. Soil Sci. 60:153-162.

Soltanpour, P.N., and S.M. Workman. 1981. Use of inductively-coupled plasma spectroscopy for the simultaneous determination of macro- and micronutrients in NH_4HCO_3-DPTA extracts of soils. p. 673-680. *In* Barnes, R.M. (ed.) International Winter Conference on Developments in Atomic Plasma Spectrochemical Analysis, San Juan, Puerto Rico. 7-11 January. Heyden, London, UK.

Taylor, A.J., C.J. Smith, and I.B. Wilson. 1991. Effect of irrigation and nitrogen fertilizer on yield, oil content, nitrogen accumulation and water use of canola (*Brassica napus* L.) Fert. Res. 29:249-260.

Uddin, M.K., M.N.H. Khan, A.S.M. Mahbub, and M.M. Hussain. 1992. Growth and yield of rapeseeds as affected by nitrogen and seed rate. Bangladesh J. Sci. Ind. Res. 27:30-38.

Walker, K.C., and E.J. Booth. 1992. Sulphur research on oilseed rape in Scotland. Sulphur Agric. 16:15-19.

Wang, Z.H., S.X. Li, and S. Malhi. 2008. Effects of fertilization and other agronomic measures on nutritional quality of crops. J. Sci. Food Agric. 88:7-23.

Wiesler, F., T. Behrens, und W.J. Horst. 1999. Einfluß von höhe, zeitpunkt and form der stickstoffdüngung sowie der sorte auf die ertragsbildung und die N-flachenbilanz bei winterraps. VDLUFA-Schriftenreihe. 52:171-174.