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Cabbage Nutritional Quality as Influenced by Planting Density and Nitrogen Fertilization

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ABSTRACT

A field experiment was conducted to investigate the effect of plant density and nitrogen fertilization levels on the growth, yield and nutritional quality of cabbage (*Brassica oleracea* L. var. *capitata*), during the two winter seasons of 2006 and 2007. Four rates of nitrogen fertilizer 0 (control), 30, 60, or 90 Kg N/feddan (1 feddan (fed) = 4200 m^2) were combined with three plant densities (2, 3, or 4 plants/drip) which resulted in a density of 4, 6, or 8 plants/m^2. Data showed that increasing both N fertilization rate and planting densities significantly increased plant height while head diameter, length, weight, edible head weight, and compactness rate were increased only with increasing N fertilization rate. However, a negative impact of the highest planting density on all these parameters was recorded. Total yield/fed significantly increased by increasing both N rate and planting density. The highest yield was obtained by the application of 90 kg N/fed combined with 8 plants/m^2. Increasing N fertilization rate increased total soluble solids (TSS) but decreased dry matter content; meanwhile, planting density did not significantly affect both of these parameters. Nitrogen, protein, and nitrate contents generally increased with increasing N fertilization rate but decreased with increasing planting density. Antioxidant capacity expressed as total phenols and vitamin C contents was positively affected by increasing N fertilization rate although it was not significantly affected by increasing planting density.

Keywords: head firmness, protein, total phenols, vitamin C, yield

INTRODUCTION

Cabbage (*Brassica oleracea* L. var. *capitata*) is an excellent source of calcium, potassium, and vitamin C. It is also an important source of antioxidants since it is rich in certain substances with high antioxidant capacity such as vitamin C (ascorbic acid), carotenoids and polyphenols (Leja *et al.* 2007). Recently, there has been increasing interest in the protective biochemical function of these phytochemicals in the prevention of oxidative damage to organisms. In the past few years, an increasing number of epidemiological studies have shown an inverse correlation between the consumption of fruit and vegetables and the incidence of degenerative diseases (Ames *et al*. 1993; Rice and Miller 1995).

Cabbage nutritional quality is highly influenced by fertilization, particularly nitrogen (N). However, the continuous fluctuation in fertilizers cost, especially of N, during the past years requires special attention and determination of the optimal fertilization levels in an effort to control the increase in production cost. Higher yields have been achieved by higher rates of fertilizer, closer spacing, new cultivars, better pest control, and attention to water management (Halsey *et al*. 1966). Cabbage is a heavy feeder, especially of N and there is experimental evidence to substantiate this belief (Din *et al*. 2007). N is one of the most important nutrients for higher yield and good quality heads. The amount and type of N fertilizer used for this crop vary in different cultivation areas, depending on soil type and nutritional conditions. Being a heavy feeder of nutrients, cabbage requires special attention for harvesting a good yield. The heads will not form unless adequate N is given (Knavel and Herron 1981). A judicious and balanced use of fertilizer can nevertheless bring about a substantial increase in crop productivity (Halsey *et al.* 1966). Furthermore, it has long been accepted that applications of N fertilizer to cabbage increased yields, plant uniformity, and quality (McCubbin 1945; Thomas *et al.* 1970).

Plant spacing also has been shown to be related to head weight and marketable yield percentage (Halsey *et al*. 1966; Shumaker 1969). There are several citations in the literature from the past three decades that provide information relative to optimum plant population evaluations for cabbage (Day 1986; Stoffela and Fleming 1990; Lal 1996; Stepanović *et al.* 2000). A very common wide range in optimum plant population recommendations for cabbage is for stand densities of 20,000-70,000 plants/ha (about 8000-28000 plants/feddan (fed); 1 feddan = 4200 m^2) (Ghanti *et al.* 1982; Tenday and Kuzyk 2001; Kumar and Rawat 2002). However, results of these reports have been inconclusive. Cabbage yield and quality response to plant density has been shown to be influenced by several factors such as plant genotype, climate condition, soil, water regime, nutrient status, market requirements and many others (Knavel and Herron 1981; Parmar *et al.* 1999; Tiwari *et al.* 2003). Increasing plant population with cabbage has the potential for increasing yield and profit. Although in cabbage, high plant density reduced head size and head weight (Csizinsky and Schuster 1985), a greater number of heads per unit area increased total yield (Stepanović *et al.* 2000).

Though many authors have reported some information on the N fertilization and plant density of different varieties of cabbage, studies under Egyptian conditions are limited. For example, investigation of Abo-Sedera *et al.* (1989) and Farghaly (1990) indicated that increasing N level significantly increased all vegetative growth characters of cabbage cv. 'Balady' as well as total head yield. Also, results of Hatem *et al.* (1996) showed that increasing plant spacing up to 60 cm and N fertilization level up to 40 kg N/fed significantly increased the individual head weight of cabbage cv. 'Balady' but the highest total head yield was obtained by

Received: 9 January, 2009. Accepted: 9 July, 2009.

Original Research Paper

planting at 30 cm with 40 kg N/fed.

As few studies have been conducted on this aspect under new reclaimed areas in Egypt, the present study was conducted to find out the optimum rate of N, and optimum plant density per drip under a drip irrigation system for cabbage cultivation. The objective of this study was to determine the response of cabbage plants to three plant densities with three N fertilization rates on yield, head size, and nutritional value aiming at high yield and good quality.

MATERIALS AND METHODS

This study was conducted during the winter seasons of 2006 and 2007 at the Experimental Station of the National Research Centre, Noubaria, Behaira Governorate, North Delta of Egypt. While preparing the field, soil samples at 25 cm depth were obtained for chemical analysis. These samples were analyzed for soil texture, EC, pH, organic matter, N, P, and K contents. The experimental soil had a sandy texture with pH of 7.6, EC of 0.18 (Ds/m in soil paste) and the organic matter content was 0.19%. Soil N, P and K contents were 15.00, 9.40, 16.00 mg/100 g soil, respectively.

Plant material

Cabbage seedlings (cv. 'Balady') were obtained from a local commercial nursery where healthy seedlings of uniform size were selected and transplanted on the 15th November, 2006 and 18th November, 2007. After one week of transplantation, dead seedlings (~5%) were replaced by planting fresh seedlings to obtain a uniform stand. A full dose of P_2O_5 (90 kg/fed) as single super phosphate (15% P_2O_5, Abo Zabal Co. for Fertilizers, Cairo, Egypt) and K_2O (60 kg/fed) as potassium sulphate (50% K_2O, SOP standared, Tessenderlo Group, Brussels, Belgium) with half a dose of the assigned N dose in the form of ammonium nitrate were applied during soil preparation, while the remaining dose of N was applied 30 days after transplanting. Regular Standard agricultural practices common in the area as recommended by Egyptian Ministry of Agriculture were followed. Irrigation was carried out regularly each other day when the water level reach about 75% of the field capacity. First hoeing and weeding was carried out 20 days after transplantation and two more weedings were carried out at one month interval. Crop was harvested when heads attained the proper size.

Treatments

Four rates of N fertilizer namely 0 (control), 30, 60, or 90 Kg N/fed (in the form of ammonium nitrate; 33% N, Abou Keer Co. for Fertilizers, Alex., Egypt) were applied. The three tested plant densities were 2, 3, or 4 plants/drip which resulted in a density of 4, 6, or 8 plants/m^2. The amount of applied N-fertilizer was divided equally into five applications, with the first one applied at pre-transplanting as basal, and the other four at 14, 21, 28 and 35 days after transplanting as side-dressing. The control received no N fertilizer. Plot size was 20 m^2, distance between rows was 100 cm and between drips was 50 cm. The number of plants per plot varied depending on the plant densities from 80 to 160 plants.

Treatments details are provided below:

T1 = 0 kg N + 4 plants/m^2	T7 = 60 kg N + 4 plants/m^2
T2 = 0 kg N + 6 plants/m^2	T8 = 60 kg N + 6 plants/m^2
T3 = 0 kg N + 8 plants/m^2	T9 = 60 kg N + 8 plants/m^2
T4 = 30 kg N + 4 plants/m^2	T10 = 90 kg N + 4 plants/m^2
T5 = 30 kg N + 6 plants/m^2	T11 = 90 kg N + 6 plants/m^2
T6 = 30 kg N + 8 plants/m^2	T12 = 90 kg N + 8 plants/m^2

Seedling mortality was compensated by gap filling even at the later stages in order to provide adequate competition using plants from the border rows. Plants transplanted at later stages (within 15 days after transplanting) were marked and excluded.

Measurements

1. Vegetative growth and yield parameters

Cabbage heads were harvested when they matured horticulturally. Horticultural maturity was assessed on the basis of head size and firmness and days after transplanting. After 70 days of planting, heads over 20 cm width and matched the normal accepted firmness measured manually (by slightly pressing over the head by hand) were harvested. Five plants were randomly selected from each treatment for determining plant height, average head diameter and length using measuring tape then average head weight was measured. The outer open leaves were removed and the head was weighed again to measure the edible head weight. Head weight was used to calculate total yield (ton/fed) depending on each planting density. Head compactness was calculated using the following formula:

$$\text{Compactness rate} = \frac{\text{Head volume } (\tfrac{3}{4}\ \pi\ \text{radius}^3)}{\text{Head weight (g)}}$$

where theoretically compactness rating of 1 means the head is very compact and it contains no air. Generally the lower the rate of compactness, the more compact the head will be and *vice versa*.

2. Head chemical quality and nutritional value parameters

Samples from each head previously used for vegetative measurement were taken to measure quality as follows:

Determination of dry matter content and TSS: sample was used to measure the dry matter content by drying 100 g of internal edible leaves at 70°C till reaching a constant weight. Also, about 10 g samples were blended and the juice was used to measure the total soluble solids using a standard ATAGO Hand-held refractometer (model MASTER-10M, ATAGO Co., Ltd., Tokyo, Japan).

Determination of N, protein, and nitrate content: N was determined spectrophotometrically using the micro-Kjeldal method (Kock and McMecking 1924). Protein content (%) was also measured spectrophotometrically using the Kjeldahl method (Rutkowska 1981). The nitrate content in the leaves was measured as described by Agbaria *et al.* (1996).

Determination of total phenolic contents: 10 g of fresh sample of cabbage internal leaves were blended then extracted with 30 ml of 80% methanol (Al-Gomhoreya Co. for Chemical Industries, Cairo, Egypt, 98%) for 20 min with agitation by a magnetic stirrer. The mixture was then filtered using Whatman No. 1 filter paper and the residue was mixed with another 30 ml of 80% aqueous methanol and the extraction process was repeated twice. The collected methanolic extracts were combined and completed to a final volume of 100 ml. The total phenolic content was measured spectrophotometrically at 725 nm using the Folin–Ciocalteu reagent (Aldrich Chemical Co. St. Louis, MO, U.S.A., Product Number F9252) (Wettasinghe and Shahidi 1999). The total phenolic content was expressed as (mg/100 g fresh weight).

Determination of vitamin C: vitamin C was determined by using the 2,6, dichlorophenol-indophenol dye (Sigma Chemical Co. St. Louis, MO, U.S.A., Product Number D1878) titration method (Nielsen 1998) where 1 g of internal fresh leaves were weighed and grounded using mortar and pestle with addition of **2** ml of metaphosphoric acetic acid (Al-Gomhoreya Co. for Chemical Industries, 95%). The mixture was filtered and the extract was made up to 10 ml with the metaphosphoric-acetic acid mixture. Five ml of the metaphosphoric-acetic acid solution was pipetted into 25 ml flask followed by 2 ml of the samples extract**.** The samples were titrated separately with the indophenol dye solution until a light rose pink persisted for 5 sec. The amount of dye used in the titration were determined and used in the calculation of vitamin C content.

Experimental design and statistical analysis

The experimental design used in the two successive seasons was a split plot design with three replicates whereas the four different N fertilizer rates were laid out in main plots while the three planting densities were distributed randomly in the sub-plots. The obtained data were statistically analyzed using ANOVA and mean separation at 5% level was done using the LSD test according to the method described by Gomez and Gomez (1984).

RESULTS AND DISCUSSION

A rapid increase in fertilizers and production costs with little increase in price of fresh produce such as cabbage has emphasized the importance of good cultural practices to reduce costs. Traditionally, cabbage growers have increased production by increasing N application rates regardless the possible hazard of such treatment on human health; furthermore, there is no established data on the best fertilization rate in the newly reclaimed land under Egyptian conditions. On the other hand, higher yields per cultivated area could be achieved by intensive cultivation. This research aims to test the effect of N application rate and plant densities on yield and nutritional quality of cabbage heads.

When the experimental data were statistically analyzed, it was noticed that the both planting seasons followed the same trend; thus the combined analysis of the two tested seasons are presented.

Vegetative growth and yield parameters

Data presented in **Table 1**, shows that N fertilization rate and planting densities significantly interacted in increasing all vegetative growth and yield parameters. Plant height was significantly increased by increasing both N fertilization rates from 30 to 90 kg N/fed and plant density from 4 to 8 plants/m^2 and there was a statistical significant interaction between both tested factors. The tallest plants were obtained by planting 8 plants/m^2 with 90 kg N/fed while shortest plants were obtained by planting 4 or 6 plants/m^2 plus 0 kg N/fed with no significant difference between the last 2 planting densities. The apparent elongation with increasing planting densities may be attributed to the increased competition for light among plants which resulted in a degree of shadding of the plants which led to stem elongation and in this case increasing N fertilization increased plant elongation. Similar results were obtained by Haque *et al.* (2006), who mentioned that plant height was significantly increased as N application rate increased. In contrast, the obtained data contradicted the findings of Sarker *et al*. (2002) who found that plant spacings (60 × 45 cm or 60 × 60 cm) had no statistical effect on plant height at different days after transplanting of cabbage cv. ‘Atlas 70’ grown in Bangladesh.

Furthermore, a similar pattern was observed with head diameter, length, weight, edible head weight, and compactness rate where N fertilization rate had a positive effect, increasing all the previously mentioned parameters. In contrast, a negative impact of plant density on all these parameters was observed since the higher the density, the lower the parameter value (**Table 1**). There was a significant interaction between N fertilization and plant density and the highest values were obtained from plants received 90 kg N/fed and planted at 4 plants/m^2 in all these parameters and the lowest ones were obtained by plants that received no N fertilization with the highest plant density (8 plants/m^2). As for head weight, similar results were obtained by White and Forbes (1976), who reported that head weight of cabbage hybrid ‘Rio Verde’, was increased with increasing plant spacing, and generally as the amount of N rate increased from 125 to 275 pounds N/acre (140 to 300 kg N/ha). Also, same trend were obtained under Egyptian conditions by Farghaly (1990) who mentioned that the highest total head yield of cabbage cv. ‘Balady’ (67.85 ton/fed) was obtained when using highest N level 134 kg N/fed with the smallest intra-raw spacing (25 cm). Also, Hatem *et al*. (1996) found that increasing plant spacing up to 60 cm and N fertilization level up to 40 kg N/fed significantly increase the head weight but the highest total yield was obtained when planting at 30 cm with 40 kg N/fed.

Head diameter generally decreased with increasing plant density as mentioned by Znidarcic *et al.* (2007) who found that head diameter of cabbage cultivars ‘Vestri’, ‘Parel’, ‘Delphi’, ‘Destiny’ and ‘Hermes’ generally decreased as plant density increased from 82,000 to 166,000 plants/ha. Semuli (2005) mentioned that as plant spacing was reduced, competition for nutrients, light, air and moisture increased, which would have resulted in a decrease in diameter and weight of cabbage heads cv. ‘Drumhead’. Stofella and Fleming (1990) reported that with increasing plant spacing from 8 to 38 cm, head length and head diameter of cabbage cv. ‘Bravo’, increased 4-folds. The increase in head diameter and weight with the reduction of plant densities may be due to the higher availability of water, light, and nutrients. Similar findings were obtained by Hossain *et al.* (1983) on cabbage cv. ‘Atlas 70’. Head compactness, which is a primary indicator of horticultural maturity (Radovich *et al.* 2004), was negatively influenced by increasing planting density. The obtained data were not in accordance with results reported by Znidarcic *et al.* (2007) who indicated that the maximum plant spacing achieved minimum head compactness.

As for total yield per fed, it was evident from data presented in **Table 1** that increasing both N rates and planting density significantly increased total yield/fed. The highest yield was obtained by increasing N rate up to 90 kg N/fed combined with 8 plants/m^2. The obtained results clearly indicated that although low planting density increased head weight but it failed to compensate the decrease in total yield and the highest yield was resulted from the higher planting

Table 1 Effect of different N fertilization rates and planting density on vegetative growth and yield parameters of cabbage (combined analysis of 2006 and 2007 seasons).

Treatments		Plant height (cm)	Head diameter (cm)	Head length (cm)	Weight of head (kg)	Edible head weight (kg)	Dry matter (%)	Compactness rate	Total yield (t/fed)
Nitrogen rates (kg/feddan)	**Plant density (plant/m^2)**								
0	4	28	21.33	18.56	1.39	0.96	8.18	2.05	23.35
	6	27	19.88	18.99	1.34	0.92	7.41	1.72	33.76
	8	28	20.65	19.56	1.21	0.8	7.21	2.14	40.65
30	4	32	26.19	22.74	1.63	1.18	10.53	3.24	27.38
	6	34	23.19	19.88	1.57	1.13	10.44	2.33	39.56
	8	36	21.23	18.66	1.48	1.06	10.32	1.9	49.72
60	4	33	28.75	23.15	1.94	1.48	9.84	3.6	32.59
	6	35	24.89	21.24	1.9	1.45	9.58	2.38	47.88
	8	36	22.97	19.16	1.64	1.41	9.12	2.17	55.10
90	4	33	29.12	23.87	1.98	1.51	8.64	3.67	33.26
	6	35	26.11	21.94	1.91	1.46	8.45	2.74	48.13
	8	38	24.15	21.23	1.65	1.43	8.22	2.51	55.44
L.S.D at 5% level		1.6	1.4	1.3	0.072	0.046	0.48	0.48	2.9

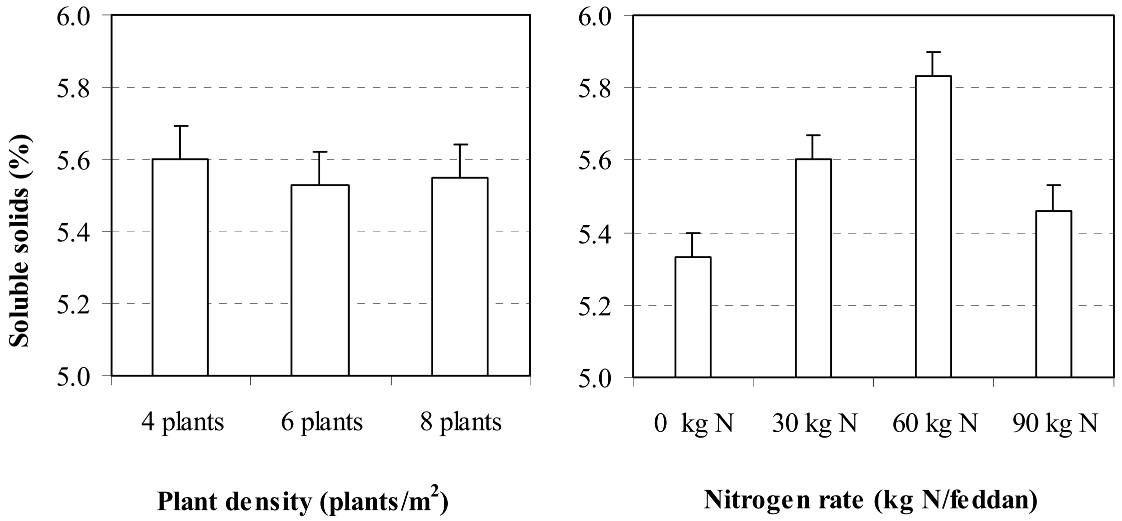

Fig. 1 Effect of nitrogen rate and plant density on soluble solids content (%) in cabbage leaves. Vertical bars present LSD value at p ≥ 5%.

density. These results match with those obtained by Khatiwada (2000) who mentioned that cabbage head yields were statistically higher (35 t/ha) at closer plant spacing (45 × 20 cm ~ 74,074 plant/ha) and Znidarcic *et al.* (2007) who stated that yield/ha generally increased about 12.5% as plant spacing increased from 108,000 to 166,000, plant/ha.

Head chemical quality and nutritional value parameters

Dry matter and TSS content

Dry matter percentage is an important consumer preference characteristic since it indicates a higher quality; moreover, consumers do not want to buy watery products. The effect of N fertilizer levels and different planting density on dry matter percentage as shown in **Table 1**, clearly indicating that there was a negative effect of N fertilization rate and planting density. A significant interaction between N fertilization and plant density was observed. The highest dry matter content was obtained from plants received 30 kg N/fed and planted at 4 plants/m^2 while the lowest one was obtained by plants received no N fertilization with the highest plant density (8 plants/m^2). These results support those of Balik *et al.* (2003), Sorensen (1999) and Yildirim *et al.* (2007) who reported that increasing N levels were associated with lower dry matter percentages in leaves, stem and heads of broccoli (*Brassica oleracea* L. var. *italica*), cabbage and maize (*Zea mays* L.), respectively. Furthermore, such results also were in agreement with those obtained by Znidarcic *et al.* (2007), who found that heads grown at high densities produce less dry matter than those grown at low densities.

A different behavior was obtained with TSS values, as noticed in **Fig. 1**. There were no statistically significant interactions between the two studied factors and when factors were analyzed individually, it was clear that TSS content increased significantly with increasing N fertilization rate up to 60 kg N/fed while increasing the rate to 90 N/fed significantly reduced TSS content. However, planting density had no significant effect on TSS content. Similar results were obtained by Znidarcic *et al.* (2007) where planting density had no statistical impact on TSS content.

Nitrogen, protein, and nitrate contents

Regarding N, protein, and nitrate contents, it is clear from the data presented in **Figs. 2**, **3**, and **4** that the general trend was the increased levels of these components with increasing N fertilization rate. On the other hand, these values decreased with increasing planting density. The interaction between the two factors was significant and the highest values were detected with the treatment received 90 kg N/fed and planted at 4 plants/m^2 while the lowest N, protein, and nitrate contents resulted in plants that received no N fertilization and were planted at 8 plants/m^2. Similar findings

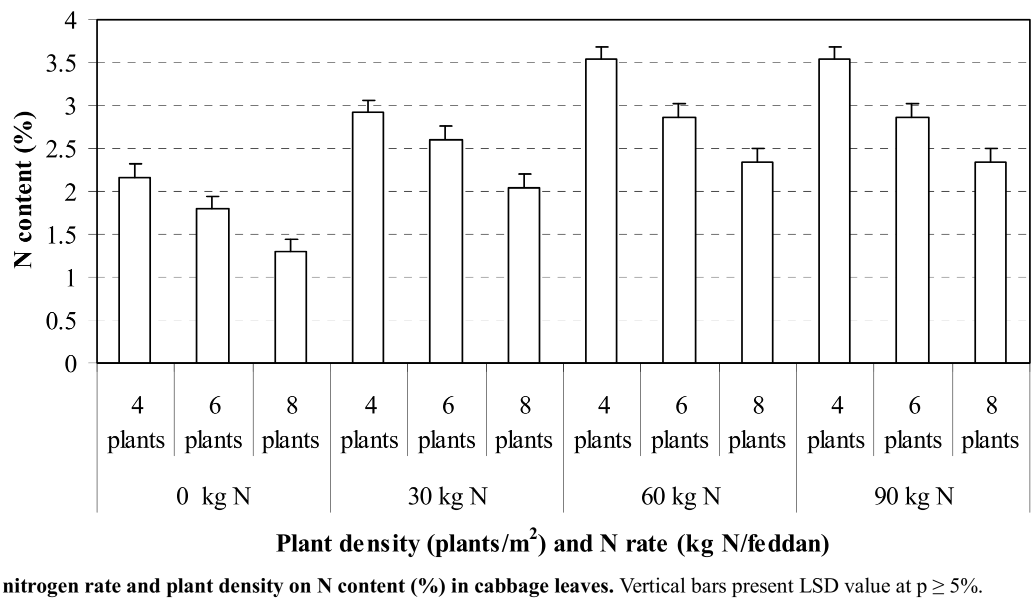

Fig. 2 Effect of nitrogen rate and plant density on N content (%) in cabbage leaves. Vertical bars present LSD value at p ≥ 5%.

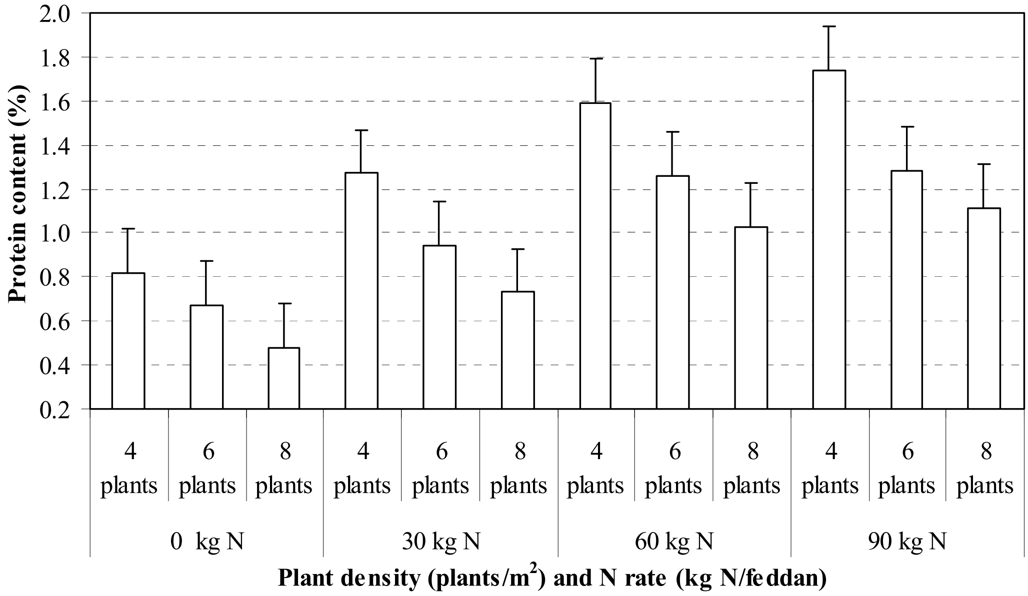

Fig. 3 Effect of nitrogen rate and plant density on protein content (%) in cabbage leaves. Vertical bars present LSD value at p ≥ 5%.

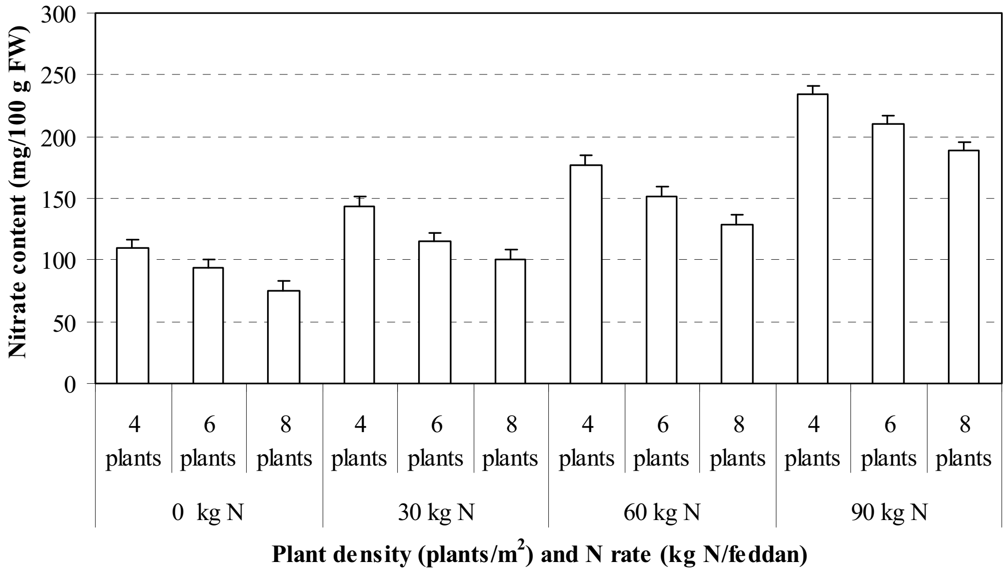

Fig. 4 Effect of nitrogen rate and plant density on nitrate content (mg/100 g FW) in cabbage leaves. Vertical bars present LSD value at p ≥ 5%.

were also reported by Karitonas (2003) who mentioned that N fertilization with 240 kg N/ha gave the optimum yield and increased the content of N to 31.3 g/kg dry weight in broccoli and also Yildirim *et al.* (2007) reported that increasing soil N fertilization from 0 to 275 kg N/ha significantly increased N content in broccoli cvs. 'AG 3317' and 'AG 3324'. However, protein content in cabbage was increased statistically from 1.34 to 1.56 g/100 g of edible portion with increasing N application rate from 60 to 180 kg/ha (Haque *et al.* 2006).

The obtained data of nitrate content were in harmony with investigations of Chen *et al.* (2004) who reported that as N supply increased from 0.00, up to 0.45 g N/kg soil, the nitrate concentration in Chinese cabbage (*Brassica chinensis* var. *oleifera* Makino et Nenoto) grown in 5 kg pots was increased in the whole plant and the different organs except in roots which where decreased with N supply at 0.60 g N/kg soil.

Total phenolic contents

The effect of the studied factors on the total phenolic content had no statistically significant interaction. It was clear from data illustrated in **Fig. 5** that N fertilization rate positively affected the total phenolic content and that increasing N fertilization rate from 0 to 90 kg N/fed significantly increased phenolic content of cabbage plants which is a common result since it is well known that increasing N fertilization usually increase phenolic compounds levels. This result agrees with a previous study by Prasad *et al.* (2006) who found that the total phenolic content of tomato (*Lycopersicon esculentum* Mill.) fruits increased from 94.16 to 280.00 mg/100 g as N fertilizer level increased from 10.86 g/m^2 to 22.174 g/m^2. Also this agrees with Delgado *et al.* (2006) who found that increasing N fertilization rate increased total polyphenols content while excessive N reduced polyphenols synthesis in berry skins of red Tempranillo grapes (*Vitis spp.*). The obtained data suggest that using 60 kg N/fed since it had an acceptable level of phenolic compounds which add a valuable nutritional value due to the known role of phenolic compounds as a powerful antioxidant.

On the other hand, **Fig 5** clearly illustrates that planting density had no significant effect on the phenolic compounds content.

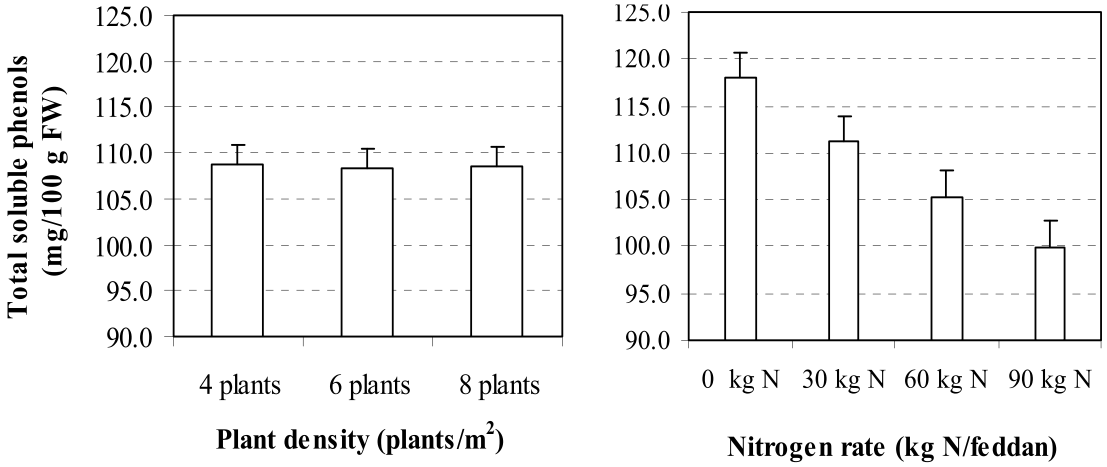

Fig. 5 Effect of nitrogen rate and plant density on total soluble phenols (mg/100 g FW) in cabbage leaves. Vertical bars present LSD value at $p \geq 5\%$.

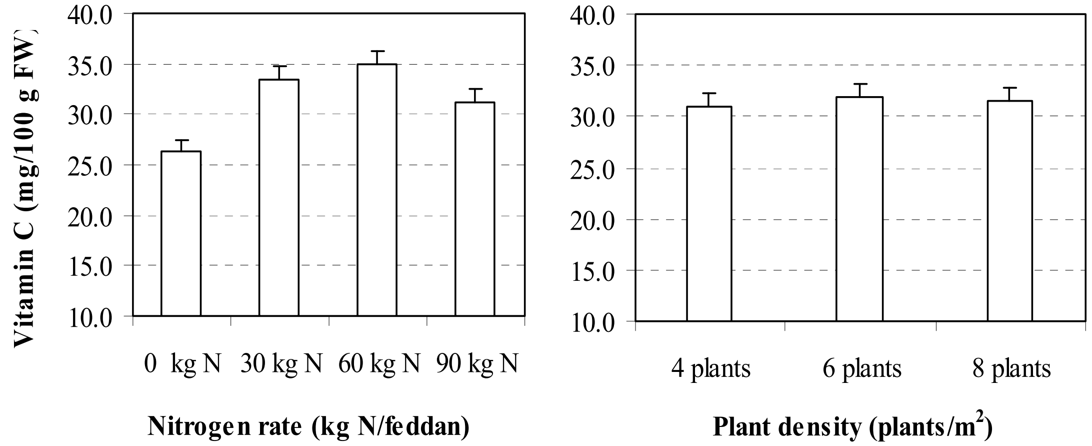

Fig. 6 Effect of nitrogen rate and plant density on cabbage leaves content of vitamin C (mg/ 100 g FW). Vertical bars present LSD value at $p \geq 5\%$.

Vitamin C content

Concerning vitamin C content, the two studied factors did not interact significantly. As shown from data presented in **Fig 6**, with increasing N fertilization rate up to 60 Kg N/fed, the vitamin C content increased while increasing fertilization to 90 kg N/fed significantly reduced the vitamin C content. Plant density did not significantly affect vitamin C content of cabbage leaves. Coincident with these findings, research data of Yildirim *et al.* (2007) indicated that increasing N fertilization rate from 0 to 275 kg N/ha lowered vitamin C content in broccoli by about 12-17% over a 3 years experiment. Also, Babik and Elkner (2002) reported that a significant decrease in ascorbic acid level in broccoli with high N fertilization (400 and 600 kg N/ha). Furthermore, Sorensen (1999) reported that increasing N supply decreased the concentration of vitamin C in cabbage.

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