Effect of foliar urea application on quality, growth, mineral uptake and yield of broccoli (*Brassica oleracea* L., var. *italica*)

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ABSTRACT

The objective of this study was to determine the effect of foliar urea applications on quality, growth, mineral content and yield of broccoli under field conditions in 2003, 2004 and 2005. Broccoli cultivars AG 3317 and AG 3324 were treated with foliar urea applications at different concentrations (0.0, 0.4, 0.8 and 1.0%). Foliar applications of urea, especially 0.8 and 1.0% resulted in larger heads, weightier heads and plants as well as higher plants. Conversely, the greatest head and leaf dry matter contents were obtained with no fertilizer-nitrogen application. SPAD chlorophyll readings that were measured in the third year increased with elevated urea concentrations. In regard to the nutrient content, it can be interfered that soil nitrogen fertilization and foliar urea applications increased the content of almost all nutrients in leaves and heads of both broccoli cultivars in three experiment years. Generally, the greatest values were obtained from 1.0% urea application for both cultivars. It results from the study that for optimum yields 0.61 and 0.96% concentrations of urea sprays could be successfully used to obtain better growth and yield in broccoli cultivars AG 3317 and AG 3324, respectively.

Keywords: broccoli; fertilization; foliar application; mineral uptake; urea; yield

Inorganic nitrogen fertilization plays an essential role in increasing broccoli yield and quality. The largest yields from field experiments were obtained with widely varying rates of N fertilizers, making the comparison, interpretation and extrapolation of the results difficult, since the soil, weather, cultivars and crop management differed. Although an apparently high demand of N for a better production has been reported, under non-optimal conditions broccoli may have lesser requirements of N; in these conditions surplus N may become a potential environmental problem (Mourao and Brito 2001). Both excess and insufficient nitrogen applications may cause either yield reduction or some physiological disorders like hollow stem, and some pathological problems like head rot in the broccoli crop (Belec et al. 2001).

The interest in foliar fertilizers arose due to the multiple advantages of foliar application methods such as rapid and efficient response to the plant needs, less product needed, and independence of soil conditions. It is also recognized that supplementary foliar fertilization during crop growth can improve the mineral status of plants and increase the crop yield (Kolota and Osinska 2001).

A high penetration rate is one of the pre-requisites for efficient foliar nutrition. Urea, due to its intrinsic characteristics such as small molecular size, non-ionic nature and high solubility, is usually taken up rapidly through the leaf cuticle. Urea can be supplied to plants through the foliage, facilitating optimal nitrogen management, which minimizes nitrogen losses to the environment. Most plants absorb foliar applied urea rapidly and hydrolyze the urea in the cytosol (Witte et al. 2002). The beneficial effects of foliar urea applications, expressed as an increase in yield and an improvement of crop quality were reported in many vegetable species such as cabbage, onion, cucumber, squash (Padem and Yildirim 1996, Kolota and Osinska 2001).

The absorption rate of mineral nutrients by aboveground plant parts considerably differs not only among plant species but also among varieties

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within the same species (Wojcik 2004). There is little information on the effect of the foliar application of urea on broccoli. Therefore, the main objective of this work was to study the effect of foliar fertilization with urea at different doses on broccoli production and quality.

MATERIAL AND METHODS

This study was conducted under field conditions at the Atatürk University, Hamza Polat Vocational Training School, in Upper Coruh Valley (Ispir) in Turkey in 2003, 2004 and 2005.

Soil physical and chemical properties of the experimental area are presented in Table 1. Before planting, samples consisting of approximately twenty cores were taken across the diagonal of the soil layers 0–30 and 30–60 cm of the experimental field, to determine the amount of mineral nitrogen (N_{min}). Soil pH was determined in 2:1 water-soil suspension by pH-meter. Exchangeable cations (K, Ca, Mg) and plant available phosphorus were determined according to the instructions given by Page et al. (1982). Organic matter and total nitrogen were also determined according to the instructions given by Page et al. (1982).

Seeds of broccoli cultivars AG 3317 and AG 3324 were sown into plastic trays filled with peat (pH:5.5, EC:250 dS/m, N:300 mg/l, P: 131 mg/l, K: 333.33 mg/l, organic matter: 2%) on 20 June 2003, and 25 June 2004 and 2005. The seedlings were initially grown in a greenhouse and fertilized with 20N-20P-20K soluble fertilizers. Seedlings (about 1-month old) were transplanted in rows (0. 50 m apart with an intra-row spacing of 0.45 m). Each plot consisted of 25 plants. During the plant-growing period, furrow irrigation was used. Insecticide was applied to avoid crop damage by cabbage worms and aphids. Weeds were kept under control manually.

The experimental design was a randomized complete block design with three replications. Treatments consisted of N_{min} (mineral nitrogen in the soil layer 0–60 cm at planting; i.e. no basal nitrogen fertilization) (Control 1), 275 kg/ha N (Control 2), 275 kg/ha N + 0.4% foliar urea, 275 kg/ha N + 0.8% foliar urea and 275 kg/ha N + 1.0% foliar urea. A basal dressing of 90 kg/ha P as triple super phosphate and 150 kg/ha K as potassium sulphate was applied before planting.

Plants were treated with 0, 0.4, 0.8 and 1.0% urea solutions that were made up with distilled water containing 0.02% Tween 20 as surfactant (Polyoxyethylenesorbitan monolaurate, Sigma Chemicals, St. Louis, MO, USA). Plants sprayed with 0.02% Tween 20 served as the control. Urea was applied with spraying using a hand-held sprayer four times during the vegetation at 10-day intervals, two weeks after planting.

Harvesting took place in September in all three years. The inner rows were used for sampling and harvest. Entire plants were harvested at ground level from each plot when the terminal buds were swollen but not opened, and were weighed. Plant height was determined by measuring from ground level to head bottom. The plants were then cut 20 cm below the top of head, which was trimmed to obtain a marketable product. Head diameter was measured across the widest part of head. The presence or absence of hollow stem was determined after cutting the stem longitudinally. Hollow stem

Table 1. Physical and chemical properties of experimental area soil

Depth	Sand	Silt	Clay	Organic matter	$CaCO_3$	N	P	pH 2:1 (S:W)	EC × 10^6 (DS/m)	Ca	Mg	K	Na
	(%)					(mg/kg)				($cmol_c$/kg)			
2003													
0–30 cm	14.3	33.8	52.5	5.18	17.11	5.4	14.18	8.3	3.05	19.54	4.50	1.80	0.50
30–60 cm	12.4	36.0	51.6	3.60	17.27	3.2	10.25	7.8	2.40	17.17	2.60	1.80	0.40
2004													
0–30 cm	53.4	14.7	31.9	1.25	10.67	8.6	7.60	8.0	2.10	11.20	4.38	1.20	0.30
30–60 cm	31.1	21.7	47.2	0.83	10.20	3.8	3.24	8.1	2.00	13.60	3.31	0.90	0.20
2005													
0–30 cm	38.4	45.5	19.7	1.31	5.90	4.6	9.28	8.3	2.05	10.86	4.20	1.10	0.42
30–60 cm	35.2	41.6	23.2	0.81	5.20	2.3	4.12	8.3	2.15	12.14	2.66	0.80	0.32

incidence was observed rarely and so the results are not shown in the study.

Dry weights (after drying at 70°C) of head and leaf samples were measured. In heads of broccoli cultivars ascorbic acid, known as vitamin C, was measured by classical titration method using 2,6-dichlorophenol indophenol solution in mg/100 g sample (Miller 1998).

The Minolta chlorophyll meter SPAD-502 was used to estimate nitrogen concentration in leaves in 2005. Nitrogen is closely related to chlorophyll in leaves, therefore SPAD readings are a good indicator of the N status in crops. SPAD chlorophyll meter readings were taken from recently fully expanded leaves for each replicate, and the same leaves were used for chemical analyses (Alcantar et al. 2002).

Chemical analyses were performed after harvest. Samples were taken from recently expanded leaves and heads of each plot. In order to determine the mineral contents of leaves and heads, plants samples were oven-dried at 70°C for 48 h and then ground. The micro-Kjeldahl procedure was applied for determination of N, K, Ca and Mg contents were determined after wet digestion of dried and ground sub-samples in a HNO_3-$HClO_4$ acid mixture. In the diluted digests, P and S were measured spectrophotometrically by the indophenol-blue method and the barium sulphate method with a spectrophotometer at 660 nm and at 440 nm, respectively, after the reaction with ascorbic acid. K and Ca contents of plants were determined by the flame photometry. Mg, Na, Fe, Mn, Zn and Cu contents were determined by the atomic absorption spectrometry using the method of AOAC (1990).

Data were subjected to the analysis of variance (ANOVA) to compare the effects of foliar urea treatments. Regression analysis was also performed on the effect of urea applications at different concentrations on total yield. When significant differences occurred, the means were separated using Duncan's least significant difference test (LSD, $P < 0.05$).

RESULTS AND DISCUSSION

Growth and quality

The present study demonstrates that foliar urea applications significantly affected the quality, growth and yield of broccoli. In the study, soil nitrogen fertilization and foliar urea application increased the head weight, head diameter, plant weight and plant height of broccoli cultivars AG 3317 and AG 3324 in all experiment years (Tables 2 and 3). Similar findings were reported by Nkoa et al. (2002) and Babik and Elkner (2002). Our results also agree with those of Guvenc et al. (1995) who found out that the foliar urea application improved some quality and growth properties of tomato.

Head dry matter and leaf dry matter contents of both cultivars were negatively affected by mineral nitrogen treatment and foliar urea applications. 1.0% urea application decreased statistically significantly ($P < 0.05$) the head dry matter content, compared to the other treatments in AG 3317. There was no significant difference between the treatments except for Control 1, in regard to leaf dry matter of AG 3317 in all three years, and of AG 3324 in 2003 and 2004; in 2005, its leaf dry matter content was lower in the case of 1.0% foliar urea application than Control 1, Control 2 and 0.4% foliar urea application (Tables 2 and 3). These results support those of Sorensen (1999) and Balik et al. (2003) who reported that increasing nitrogen levels were associated with lower dry matter percentages in leaves, stem and heads of broccoli, cabbage and maize. Busada et al. (1984) indicated that foliar nitrogen applications caused a decrease of dry matter content in root, stem and leaves of snap beans.

SPAD chlorophyll meter values increased with increasing urea concentration for both cultivars. SPAD chlorophyll meter readings in both broccoli cultivars were correlated with tissue total nitrogen concentrations determined by the laboratory analysis, which means that chlorophyll meter readings gave the increased values with increasing urea doses (Tables 2 and 3). The effect of soil nitrogen treatment and foliar urea applications on chlorophyll readings in the study is in good agreement with the results of Villeneuve et al. (2002) in broccoli and with Westerveld et al. (2003) in cabbage. They proved that SPAD chlorophyll meter readings in leaves were correlated with tissue total nitrogen concentrations. This phenomenon may cause that the addition of mineral nitrogen or foliar urea application increase the total nitrogen content in leaves.

A statistically significant effect of soil nitrogen fertilization and foliar urea application on the level of vitamin C was found in both cultivars in all three years (Tables 2 and 3). In both cultivars, vitamin C content decreased with the application of mineral nitrogen and elevated foliar urea compared to Control 1 in all experiment years.

Table 2. Effect of foliar urea applications on quality and growth characteristics of broccoli cultivar AG 3317

Treatments	Head weight (g)	Head diameter (cm)	Plant weight (g)	Plant height (cm)	Head dry matter (%)	Leaf dry matter (%)	SPAD chlorophyll reading	Vitamin C (mg/100 g)
2003								
Control 1	460 c^z	14.1 b^z	1646 c^z	34.70 b^z	12.30 a^z	15.23 a^z	–	81 a^z
Control 2	557 b	17.1a	1941 b	40.10 a	11.90 b	14.20 b	–	72 bc
Urea 0.4%	566 b	17.1 a	1968 b	41.10 a	11.70b	14.32 b	–	72 bc
Urea 0.8%	591 a	17.6 a	2171 a	39.20 ab	11.60 b	14.19 b	–	74 b
Urea 1.0%	555 b	17.1 a	1934 b	40.30 a	10.20 c	14.13 b	–	65 c
LSD (0.05)	19.51	0.53	160.91	4.56	0.38	0.37	–	7.05
2004								
Control 1	327 d^z	9.39 c^z	1365 d^z	30.84 d^z	14.35 a^z	17.15 a^z	–	115 a^z
Control 2	441 c	13.09 b	1696 c	33.79 c	13.58 b	15.73 b	–	98 b
Urea 0.4%	451 bc	12.87 b	1809 b	35.75 b	13.79 ab	15.88 b	–	94 b
Urea 0.8%	497 a	13.86 a	1855 a	36.78 a	13.52 b	16.10 b	–	93 b
Urea 1.0%	471 b	12.56 b	1702 c	36.77 a	12.94 c	16.15 b	–	87 b
LSD (0.05)	23.13	0.56	42.92	0.67	0.58	0.88	–	16.24
2005								
Control 1	313 d^z	8.24 c^z	1164 d^z	28.31 d^z	13.32 a^z	18.26 a^z	56.32 e^z	88 a^z
Control 2	442 c	13.48 b	1599 c	35.16 c	12.73 b	16.18 b	64.62 d	77 b
Urea 0.4%	472 b	13.77 b	1747 b	36.15 bc	12.41 bc	15.88 b	68.88 c	71 c
Urea 0.8%	510 a	14.46 a	1853 a	37.11 b	12.51 bc	15.59 b	72.72 b	75 b
Urea 1.0%	482 b	13.54 b	1779 b	38.77 a	12.35 c	15.77 b	75.85 a	69 d
LSD (0.05)	11.02	0.37	53.58	1.24	0.54	1.19	2.19	1.99

Control 1 = no fertilizer, Control 2 = 275 kg N/ha; ^{z}numbers with the same letters are not statistically different according to the Duncan's Multiple Range Test ($P < 0.05$)

Table 3. Effect of foliar urea applications on quality and growth characteristics of broccoli cultivar AG 3324

Treatments	Head weight (g)	Head diameter (cm)	Plant weight (g)	Plant height (cm)	Head dry matter (%)	Leaf dry matter (%)	SPAD chlorophyll reading	Vitamin C (mg/100 g)
2003								
Control 1	625 d^z	12.77 d^z	1663 c^z	25.17 c^z	11.89 a^z	16.49 a^z	–	122 a^z
Control 2	751 c	15.80 c	2048 b	33.57 b	10.83 b	14.47 b	–	108 bc
Urea 0.4%	809 b	17.64 b	2104 ab	34.91 b	10.91 b	14.98 b	–	108 bc
Urea 0.8%	842 a	19.07 a	2211 a	36.30 ab	10.91 b	15.19 b	–	113 b
Urea 1.0%	794 b	18.16 ab	2068 b	58.63 a	10.66 b	14.87 b	–	105 c
LSD (0.05)	25.65	0.93	115.50	3.11	0.85	1.00	–	7.02
2004								
Control 1	444 c^z	11.29 c^z	1221 c^z	27.49 b^z	13.79 a^z	17.55 a^z	–	139 a^z
Control 2	608 b	14.69 b	1603 b	30.50 a	12.82 b	16.81 ab	–	121 b
Urea 0.4%	623 b	15.35 ab	1706 a	31.10 a	12.72 b	16.52 b	–	119 b
Urea 0.8%	661 a	16.20 a	1780 a	32.32 a	12.53 b	16.33 b	–	121 b
Urea 1.0%	670 a	15.89 a	1753 a	31.71 a	12.33 b	16.33 b	–	119 b
LSD (0.05)	16.88	1.10	82.42	2.32	0.47	0.90	–	9.24
2005								
Control 1	448 c^z	11.13 d^z	1245 d^z	26.17 b^z	13.32 a^z	18.31 a^z	63.05 e^z	128 a^z
Control 2	708 b	15.37 c	1733 c	31.20 a	12.66 b	17.21 b	67.76 d	108 c
Urea 0.4%	723 b	15.50 c	1766 bc	31.58 a	12.16 bc	16.74 bc	71.06 c	111 bc
Urea 0.8%	767 a	17.17 a	1857 a	32.78 a	11.63 c	16.13 cd	74.67 b	117 b
Urea 1.0%	759 a	16.42 b	1796 b	32.71 a	11.83 bc	15.80 d	78.12 a	114 bc
LSD (0.05)	15.29	0.46	46.25	2.13	0.95	0.82	2.81	7.14

Control 1 = no fertilizer, Control 2 = 275 kg N/ha; ^{z}numbers with the same letters are not statistically different according to the Duncan's Multiple Range Test ($P < 0.05$)

The greatest vitamin C values were obtained from Control 1 treatment for both cultivars in 2003, 2004 and 2005. AG 3324 contained more vitamin C than AG 3317 in all years (Tables 2 and 3). Similar observations were made by Sorensen (1999) and Babik and Elkner (2002) who found out that increasing nitrogen application lowered the vitamin C content in broccoli and cabbage.

Nutrient content

As it results from Tables 4 and 5, soil nitrogen fertilization and elevated foliar urea applications increased the content of almost all nutrients in leaves of both broccoli cultivars in all three experiment years. Generally, the greatest values were obtained from 1.0% urea application for both cultivars. N, P and K contents in AG 3317 and AG 3324 increased with increasing urea doses. The same situation occurred in Ca, Mg, S and Fe contents in all years. Mn and Zn values were inconsistent between years and cultivars. However, foliar urea applications always gave greater Cu contents in leaves of broccoli than Control 1.

Similar to the concentrations of some macro- and micronutrients in broccoli leaves, the addition of both mineral nitrogen into soil and foliar urea applications generally increased the mineral content in broccoli heads of both cultivars (Tables 6 and 7). The greatest N content in heads of both cultivars was obtained from 1.0% urea application. Turan and Sevimli (2005) reported that the nitrogen amount equalling to 1.0% urea application rate could not present a health risk for human nutrition with regard to NO_3 (1650 mg/plant) content in cabbage. Different urea applications increased the P content in heads of both cultivars in all experiment years. There were significant differences between the treatments in the case of K content in heads in the study; both soil nitrogen fertilization and foliar urea application caused an increase of K content in heads of AG 3317 and AG 3224. In terms of Ca, Mg, S and Fe content, plants treated with foliar urea, especially 0.8 and 1.0%, had usually higher concentrations than Control 1 and Control 2 (275 kg N/ha). The effect of the treatments on Mn was inconsistent, depending on years and cultivars. Apparently, 0.8 and 1.0% foliar urea applications gave higher Zn and Cu content in heads of both cultivars than other treatments used in the study. Vagen (2003) reported that nitrogen uptake in broccoli plants appears to increase with increasing fertilizer nitrogen application. The data obtained in this study concur with those of Karitonas (2003) who showed that mineral soil nitrogen fertilization increased N, P, K, Ca and Mg concentrations in leaves of broccoli. In addition, it was observed that foliar urea applications elevated the N and K content in lettuce (Padem and Alan 1995), and N, K and Fe content in tomato (Alan and Padem 1994).

In fact, it was determined that foliar fertilization does not replace soil-applied fertilizer completely but it does increase the uptake and hence the efficiency of the nutrients applied to the soil (Tejada and Gonzalez 2004). One of the benefits of foliar fertilization is the increased uptake of nutrients from the soil. This notion is based on the belief that the foliar fertilization causes the plant to release more sugars and other exudates from its roots into the rhizosphere. Beneficial microbial populations in the root zone are stimulated by the increased availability of these exudates. In turn, this enhanced biological activity increases the availability of nutrients, disease-suppressive biochemicals, vitamins, and other factors beneficial to the plant. Fritz (1978) pointed out that a repeated application of small units of foliar fertilizers stimulates plant metabolism and an increased nutrient uptake via the roots can be observed. It was concluded that the absorption of urea by the leaves of most crops is greater and faster than that of inorganic nitrogen forms. This phenomenon is related to the fact that the cuticular membrane is 10 to 20 times more permeable to urea than to inorganic ions (Wojcik 2004). Our results support the previous reports.

Yield

The response of broccoli cultivars to foliar spray of urea during the vegetative development appears to be positive (Figures 1 and 2). The yield of cultivar AG 3317 and AG 3324 were significantly ($P < 0.05$) influenced by soil nitrogen fertilization and foliar urea applications in 2003, 2004 and 2005. For cultivar AG 3317, the greatest yield occurred in 0.8% urea applications with 26 267, 22 089 and 22 667 kg/ha in three successive years, respectively. Furthermore, Control 2 gave a higher yield compared to Control 1 (Figures 1 and 2). Similarly 0.8% foliar urea application caused a significantly increased yield in AG 3324 with 37 422 in 2003. However, in 2004 and 2005 there was no significant difference between 0.8% and 1.0% applications. While 0.8 and 1.0% urea applica-

Table 4. Effect of foliar urea applications on leaf mineral content of broccoli cultivar AG 3317

Treatments	N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu
	(%)						(mg/kg)			
2003										
Control 1	2.59 d^z	0.25 c^z	1.81 c ^{z}	0.56 c^z	0.26 b^z	0.16 d^z	149 c^z	31 c^z	71 a^z	13 d^z
Control 2	2.89 c	0.39 b	1.82 bc	0.62 b	0.26 b	0.18 cd	172 b	36 b	70 a	18 c
Urea 0.4 %	3.17 b	0.40 b	1.85 b	0.68 a	0.35 a	0.20 bc	155 c	40 ab	63 bc	21 bc
Urea 0.8%	3.25 b	0.42 ab	1.92 a	0.69 a	0.32 a	0.22 b	152 c	43 b	60 c	22 b
Urea 1.0%	3.39 a	0.45 a	1.96 a	0.71 a	0.33 a	0.27 a	184 a	40 ab	67 ab	25 a
LSD (0.05)	0.09	0.04	0.04	0.06	0.04	0.03	6.54	4.25	5.24	2.73
2004										
Control 1	2.35 e^z	0.23 d^z	1.75 b^z	0.51 d^z	0.21 c^z	0.13 c^z	138 c^z	37 b^z	60 b^z	13 b^z
Control 2	2.53 d	0.31 c	1.83 b	0.62 c	0.30 b	0.12 c	143 b	40 ab	54 c	10 c
Urea 0.4%	3.25 c	0.33 c	1.80 b	0.73 b	0.34 ab	0.19 b	144 b	44 a	57 bc	15 b
Urea 0.8%	3.35 b	0.35 b	1.85 b	0.72 b	0.38 a	0.26 a	158 a	45 a	65 a	14 b
Urea 1.0%	3.45 a	0.38 a	2.02 a	0.79 a	0.38 a	0.26 a	157 a	47 a	65 a	18 a
LSD (0.05)	0.08	0.03	0.11	0.05	0.05	0.02	5.55	6.67	4.42	2.70
2005										
Control 1	2.40 e^z	0.24 d^z	1.65 c^z	0.58 c^z	0.26 d^z	0.12 d^z	122 e^z	30 e^z	62	11 c^z
Control 2	3.21 d	0.34 c	1.81 b	0.63 bc	0.24 d	0.12 d	128 d	35 d	61	12 c
Urea 0.4%	3.41 c	0.38 b	1.88 ab	0.67 b	0.39 c	0.23 c	140 c	43 c	65	18 b
Urea 0.8%	3.54 b	0.49 a	1.90 a	0.87 a	0.46 b	0.26 b	169 b	52 b	68	16 b
Urea 1.0%	3.65 a	0.51 a	1.89 a	0.87 a	0.50 a	0.31 a	175 a	62 a	69	25 a
LSD (0.05)	0.07	0.03	0.06	0.07	0.03	0.03	5.88	3.50	n.s.	3.16

Control 1 = no fertilizer, Control 2 = 275 kg N/ha; ^{z}numbers with the same letters are not statistically different according to the Duncan's Multiple Range Test ($P < 0.05$); n.s. = non significant

Table 5. Effect of foliar urea applications on leaf mineral content of broccoli cultivar AG 3324

Treatments	N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu
	(%)						(mg/kg)			
2003										
Control 1	2.90 d^z	0.30 c^z	1.82 c	0.59 d^z	0.28 c^z	0.18 b^z	166 c^z	34 d^z	63	15 c^z
Control 2	2.86 d	0.45 ab	1.88 b	0.62 c	0.25 d	0.20 b	177 b	33 d	66	18 b
Urea 0.4%	3.06 c	0.39 b	1.90 b	0.68 ab	0.29 bc	0.18 b	182 b	41 c	66	18 b
Urea 0.8%	3.17 b	0.50 a	1.88 b	0.66 b	0.31 b	0.26 a	176 d	49 b	69	24 a
Urea 1.0%	3.33 a	0.48 a	2.00 a	0.70 a	0.42 a	0.28 a	190 a	55 a	71	24 a
LSD (0.05)	0.10	0.07	0.05	0.03	0.03	0.03	7.89	3.13	n.s.	2.87
2004										
Control 1	2.40 e^z	0.20 d^z	1.78 c^z	0.48 c^z	0.23 c^z	0.11 d^z	130 c^z	39 c^z	58	10 b^z
Control 2	2.64 d	0.26 c	1.84 b	0.53 bc	0.27 b	0.12 d	136 c	36 c	60	13 a
Urea 0.4%	3.16 c	0.30 b	1.85 ab	0.62 ab	0.35 a	0.14 c	148 b	45 b	59	13 a
Urea 0.8%	3.48 b	0.32 b	1.89 ab	0.68 a	0.36 a	0.20 b	148 b	44 b	60	16 a
Urea 1.0%	3.63 a	0.36 a	1.90 a	0.72 a	0.37 a	0.24 a	167 a	59 a	64	15 a
LSD (0.05)	0.13	0.04	0.05	0.10	0.04	0.03	7.75	3.30	n.s.	2.85
2005										
Control 1	2.46 e^z	0.25 c^z	1.60 c^z	0.57 c^z	0.21 e^z	0.14 c^z	119 e^z	32 c^z	61 bc^z	11 c^z
Control 2	2.60 d	0.27 c	1.69 c	0.48 d	0.25 d	0.14 c	129 d	34 c	59 c	14 b
Urea 0.4%	3.33 c	0.35 b	1.84 b	0.65 b	0.38 c	0.16 c	140 c	46 b	66 ab	15 b
Urea 0.8%	3.57 b	0.43 a	1.89 ab	0.83 a	0.42 b	0.23 b	164 b	48 b	64 abc	18 a
Urea 1.0%	3.84 a	0.43 a	1.98 a	0.85 a	0.45 a	0.27 a	172 a	63 a	68 a	19 a
LSD (0.05)	0.11	0.04	0.12	0.05	0.03	0.03	5.71	4.64	5.43	2.19

Control 1 = no fertilizer, Control 2 = 275 kg N/ha; ^{z}numbers with the same letters are not statistically different according to the Duncan's Multiple Range Test ($P < 0.05$); n.s. = non significant

Table 6. Effect of foliar urea applications on head mineral content of broccoli cultivar AG 3317

Treatments	N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu
	(%)						(mg/kg)			
2003										
Control 1	1.88 e^z	0.21 d^z	1.45 e^z	0.93 d^z	0.15 d^z	0.11 d^z	84 b^z	22 c^z	64 c^z	10 c^z
Control 2	2.10 d	0.24 c	2.20 d	1.02 c	0.21 c	0.15 c	88 b	24 c	64 c	12 b
Urea 0.4%	2.79 c	0.23 c	3.09 c	1.19 b	0.23 c	0.20 b	97 a	28 b	66 c	12 b
Urea 0.8%	3.64 b	0.29 b	3.31 b	1.18 b	0.27 b	0.21 b	99 a	29 b	70 b	15 a
Urea 1.0%	3.82 a	0.32 a	3.74 a	1.50 a	0.39 a	0.29 a	103 a	37 a	74 a	13 b
LSD (0.05)	0.14	0.02	0.10	0.07	0.04	0.03	7.51	3.30	2.89	1.38
2004										
Control 1	2.02 d^z	0.17 d^z	1.45 d^z	0.88 e^z	0.18 c^z	0.18 b^z	94 c^z	42 a^z	44 d^z	9 b^z
Control 2	2.57 c	0.22 c	2.58 c	0.93 d	0.20 c	0.25 a	94 c	16 e	53 c	10 b
Urea 0.4%	3.02 b	0.31 b	3.41 ab	1.16 c	0.27 b	0.27 a	116 b	26 c	59 b	9 b
Urea 0.8%	3.14 b	0.31 ab	3.34 b	1.21 b	0.27 b	0.25 a	120 b	23 d	52 c	9 b
Urea 1.0%	3.76 a	0.33 a	3.47 a	1.26 a	0.33 a	0.27 a	136 a	37 b	65 a	13 a
LSD (0.05)	0.13	0.02	0.08	0.05	0.04	0.04	5.37	3.62	4.02	2.44
2005										
Control 1	1.14 d^z	0.17 c^z	2.88 d^z	0.88 c^z	0.20 d^z	0.20 d^z	84 e^z	42 a^z	52 c^z	9 b^z
Control 2	1.57 c	0.21 b	3.03 c	1.13 c	0.25 c	0.26 c	95 d	16 e	53 c	10 b
Urea 0.4%	2.00 b	0.20 b	3.29 b	1.17 b	0.30 b	0.26 c	110 c	27 c	59 b	9 b
Urea 0.8%	2.76 a	0.30 a	3.20 b	1.24 a	0.29 b	0.33 b	126 b	23 d	64 a	13 a
Urea 1.0%	2.88 a	0.29 a	3.45 a	1.29 a	0.32 a	0.37 a	134 a	37 b	65 a	15 a
LSD (0.05)	0.14	0.03	0.11	0.06	0.02	0.02	7.56	3.56	3.90	2.36

Control 1 = no fertilizer, Control 2 = 275 kg N/ha; ^{z}numbers with the same letters are not statistically different according to the Duncan's Multiple Range Test ($P < 0.05$)

Table 7. Effect of foliar urea applications on head mineral content of broccoli cultivar AG 3324

Treatments	N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu
	(%)						(mg/kg)			
2003										
Control 1	2.02 e^z	0.22 d^z	1.36 c^z	0.97 e^z	0.17d^z	0.17 b^z	87 c^z	21 d^z	64 b^z	10 c^z
Control 2	2.16 d	0.25 c	2.15 b	1.08 d	0.20 c	0.20 b	91 bc	25 c	71 a	12 b
Urea 0.4%	2.81 c	0.27 b	3.44 a	1.21 c	0.21 c	0.22 b	95 b	30 b	71 a	10 c
Urea 0.8%	3.61 b	0.30 a	3.37 a	1.35 b	0.23 b	0.32 a	101 a	33 a	70 a	14 a
Urea 1.0%	3.90 a	0.30 a	3.64 a	1.46 a	0.28 a	0.35 a	104 a	34 a	73 a	12 b
LSD (0.05)	0.14	0.02	0.40	0.07	0.02	0.05	6.63	2.25	3.53	1.14
2004										
Control 1	2.11 d^z	0.17 e^z	1.58 d^z	0.85 d^z	0.18 c^z	0.17 d^z	87 c^z	21 c^z	44 b^z	9 b^z
Control 2	2.44 c	0.22 d	2.14 c	1.00 c	0.21 c	0.21 c	94 c	19 c	57 a	10 b
Urea 0.4%	2.41 c	0.26 c	2.85 b	1.11 b	0.26 b	0.26 b	109 b	20 c	56 a	8 b
Urea 0.8%	3.25 b	0.37 b	2.83 b	1.29 a	0.28 ab	0.30 a	125 a	32 b	59 a	13 a
Urea 1.0%	3.69 a	0.47 a	3.05 a	1.29 a	0.31 a	0.32 a	130 a	36 a	59 a	13 a
LSD (0.05)	0.16	0.03	0.17	0.07	0.03	0.04	9.01	1.99	6.85	1.42
2005										
Control 1	2.02 e^z	0.22 b^z	2.22 d^z	0.86 c	0.18 d^z	0.19 c^z	87 b^z	21 c^z	64 ab^z	9 b^z
Control 2	2.33 d	0.22 b	2.85 c	1.14 b	0.21 c	0.30 b	94 b	19 c	57 bc	10 b
Urea 0.4%	2.58 c	0.18 c	3.07 b	1.14 b	0.26 b	0.33 b	85 b	20 c	56 c	8 b
Urea 0.8%	2.66 b	0.27 a	3.10 b	1.36 a	0.27 b	0.38 a	122 a	32 b	59 bc	13 a
Urea 1.0%	2.73 a	0.27 a	3.27 a	1.39 a	0.30 a	0.42 a	130 a	36 a	70 a	13 a
LSD (0.05)	0.05	0.02	0.13	0.05	0.03	0.04	9.52	1.99	6.81	1.42

Control 1 = no fertilizer, Control 2 = 275 kg N/ha; ^{z}numbers with the same letters are not statistically different according to the Duncan's Multiple Range Test ($P < 0.05$)

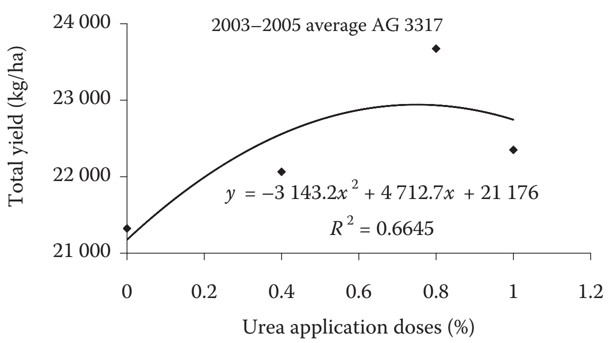

Figure 1. Effect of foliar urea applications on yield of broccoli cultivar AG 3317

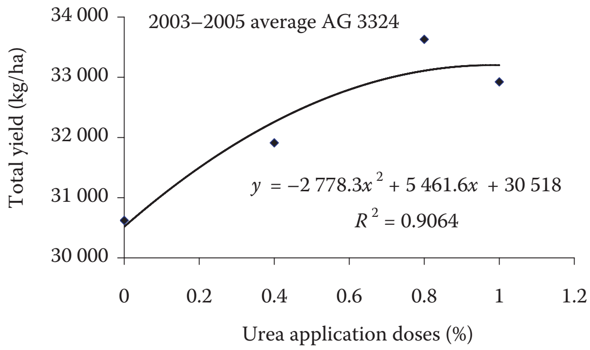

Figure 2. Effect of foliar urea applications on yield of broccoli cultivar AG 3324

tions increased significantly the yield of AG 3324 compared to the Control 1 and Control 2 in 2004 and 2005, 0.4% urea application increased the yield of AG 3324 compared to the Control 1 and Control 2 in 2003, as well (Figures 1 and 2). The positive effect of nitrogen fertilization on yield in this study is in agreement with the results of Babik and Elkner (2002), and Svoboda and Haberle (2006). Furthermore, Kolota and Osinska (2001) concluded that a multi-component foliar fertilizer containing N significantly increased the yield of cabbage. The high efficiency of foliar urea application found in this study is in agreement with the findings of Zahran and Abdoh (1998) for onion, and Zeidan (2003) for faba bean. The latter recommended that urea might be used as foliar nitrogen source to obtain better growth and yield.

Determination of optimum foliar urea application

The yield data were used to determine the optimum urea application. The response of yield to urea applications is given in Figures 1 and 2. In evaluating the urea effects yield data were pooled over 3 years of study. Broccoli yield increased quadratically with increasing urea concentrations. Based on the regression analysis of yield response data for the urea application over a range of N rates from 0.0 to 1.0%, the optimum urea concentration under this experimental condition was about 0.61% for AG 3317 and 0.96% for AG 3324.

In conclusion, foliar urea applications can result in an increase in the productivity of broccoli. The results of the present study indicate that foliar urea application would be an advisable treatment that produces higher yields in broccoli. Based on these findings 0.61 and 0.96% foliar application may be advised to obtain better quality and yield for broccoli cultivars AG 3317 and 3324, respectively, provided that an optimal management of fertilizer application is followed.

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