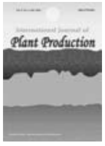

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Nitrogen, season and cultivar affect radish growth, yield, sponginess and hollowness

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Abstract

The optimization of nitrogen application for root crops such as radish is important not only for yield and product quality (sponginess and hollowness) but also for the environment. Therefore, we evaluated the effect of four levels of N application (0, 150, 300 and 450 mg l^{-1} N) on three radish cultivars (Saxa, Red Fuoko and White Ghiaccio) grown in pots in autumn/winter (from mid-October to mid-January) and spring (from mid-February to early May). The number of leaves per plant and mean leaf area increased with N rates of up to 300 mg l^{-1} in the autumn/winter and 150 mg l^{-1} in the spring. Mean root fresh weight increased with N application up to 300 mg l^{-1} (cv. Red Fuoko and White Ghiaccio) or 450 mg l^{-1} (cv. Saxa) in the autumn/winter crop, but only up to 150 mg N l^{-1} in the spring crop, irrespective of cultivar, and high N (450 mg l^{-1}) reduced the root weight of cv. White Ghiaccio in both seasons. Increasing N, however, caused a reduction in percent root dry matter and root firmness, even from as low as 150 mg l^{-1} N. The occurrence of hollowness within the roots was particularly high in White Ghiaccio, followed by Red Fuoko, whereas cv. Saxa was resistant to this defect. Red Fuoko showed a higher percentage of roots with hollow centres with increasing N levels during the winter. We conclude that although N application (up to 300 mg l^{-1} in the autumn/winter and 150 mg l^{-1} in the spring) increases yield, it may adversely affect root quality by reducing firmness.

Keywords: *Raphanus sativus*; Radish root firmness; Root hollowness; Root sponginess; Nitrogen fertilizer rate.

Introduction

Radish (*Raphanus sativus* L.) is a rapidly growing crop that is cultivated for its edible, swollen roots (derived from hypocotyl and upper radicle tissues) during winter or spring in the Mediterranean region. Although the life cycle of radish is short, it nevertheless has a high demand for nutrients. For example, to produce 1000 kg radishes requires 3.49, 0.39 and 3.46 kg N, P and K respectively (Xu et al., 2004); while all year round production under cover in the Netherlands at a very high plant density has an appreciably higher fertilizer requirement (Sonneveld and van den Bos, 1995).

The application of N promotes the growth and yield of radish (Barker et al., 1983), with recommended application rates being about 100 kg N Ha^{-1}. At higher levels of N, such as 200 kg N Ha^{-1}, root size and yield is improved, but N (particularly NO_3^-) accumulation occurs (Guvenc, 2002; Nieuwhof and Jansen, 1993), which may be considered harmful for human consumption.

Root quality of radish may be adversely affected by the occurrence of sponginess and the formation of internal cavities due to necrosis of the xylem parenchyma cells and the breakage of the xylem vessels under the influence of rapid root elongation and increasing root size (Joyce et al., 1983; Kano and Fukuoka, 1991).

The diameter but not the length of the root is found to be closely correlated with the incidence of hollow radish roots. In general, all the environmental, cultural and genotypic factors leading to rapid root growth also induce sponginess and increase the occurrence of root hollowness (Marcelis et al., 1997; Sonneveld and van den Bos, 1995). For example, this defect is higher in cultivars that form large roots, such as "daicons" (Harris et al., 2000; Hogendonk et al., 1990) and is more prevalent in summer than in spring or autumn (Harris et al., 2000; Nguyen et al., 1999) due to higher soil temperature (Fukuoka and Kano, 1997; Kano, 1989). Sponginess and hollowness also increase under sparse planting (Kano and Fukuoka, 1991) and as a result of delays in harvest (Park and Fritz, 1990) and limitations in water supply during rapid root growth (Joyce et al., 1983).

The rate and type of nitrogen fertilization seriously affects sponginess and hollowness of radish roots, with increasing fertilizer levels promoting hollowness and ammonium sulphate being more effective in preventing sponginess than ammonium nitrate or urea (Fukuoka and Kano, 1997; Park and Fritz, 1990). On the other hand, as much as 50% of the nitrogen applied as fertilizer may not be taken up by plants and this can result in leaching of nitrate into underground water (Galbiatti et al., 2007), hence the limitation of nitrogen application to vegetable field crops such as radish may be both cost-effective and beneficial for the environment.

In this study the combined effect of genotype, cultivation season and rate of N application on the growth, yield and in particular on the occurrence of sponginess and hollowness was evaluated, in a field experiment under the climatic conditions of Greece, in an attempt to determine the optimal rate of N fertilization for both yield and quality of radish roots.

Materials and Methods

Three radish cultivars [Saxa (round red), Red Fuoko (long red) and White Ghiaccio (long white)] were cultivated in the open at the Agricultural University of Athens during the autumn/winter, from mid October to mid January, and spring, from mid February to early May. Seeds were sown on 15 October for the autumn/winter crop and on 17 February for the spring crop, in plastic palettes filled with peat (Klasmann KTS1, Klasmann-Deilmann GmbH, Geeste, Germany). After 2 weeks, each plant was individually transplanted to 2l black, plastic pots containing peat (Klasmann KTS 1) and perlite (1:1 v/v) to which were added 750 g 0N-48P-0K (triple superphosphate) and 350 g K_2SO_4 per m^3. Total N in the base dressing derived from the compost was 0.32 g per pot, irrespective of subsequent treatments. Pots were placed in rows 40cm apart in the autumn/winter crop and 30 cm apart in the spring crop, and the distance between pots on each row was 10 cm in the autumn/winter crop and 7.5 cm in the spring crop, resulting in 25 and 45 plants m^{-2} respectively. Treatments consisted of four levels of N (0, 150, 300 and 450 mg l^{-1} N) applied in the form of NH_4NO_3, according to the plants' requirements for irrigation (500 ml per plant in each irrigation). The lower plant density in the autumn/winter crop was to compensate for reduced light levels during this season, compared with the spring. Given the number of irrigations per crop, the plants of the autumn/winter crop received 11, 22 and 33 kg N Ha^{-1} and those of the spring crop 72, 144 and 217 kg N Ha^{-1} at 150, 300 and 450 mg l^{-1} N respectively. The pots were randomly placed in 5 experimental plots each containing four plants.

Harvesting took place when the diameter of the root attained its maximum value and did not further increase within a 3-4 day period. Based on this criterion, plants of cv. Saxa were harvested at 63 and 69 days after sowing in the autumn/winter and spring crops respectively, Red Fuoko at 87 and 77 days after sowing and White Ghiaccio at 92 and 79 days. Throughout the cultivation period air temperature in the field was recorded at 10 minute intervals with the aid of a Hobo Weather Station (Onset Computer Corp., Pocasset, MA, USA).

The number, fresh weight and dry weight of leaves, and the ratio of leaf dry matter to leaf area were measured at harvest. Leaf area was measured using a LI-COR LI 3100 Leaf Area Meter (LI-COR, Lincoln, NE, USA). The fresh and dry weight of the root were measured, and internal root firmness evaluated by piercing the center of a 2.5-3.0 cm slice of the root, cut midway between the distal and apical ends of the root, with a conical needle (6.3 mm diameter) attached to a force gauge (Chatillon DFIS 10, connected to a TCM 201-M drive operating vertically at a penetration speed of 20 mm min^{-1}, John Chatillon and Sons, Greensboro, NC, USA). Penetration depth was 0.6 cm. The occurrence of internal cavities in the roots was recorded visually after slicing roots longitudinally into two halves.

The results were subjected to analysis of variance and means were compared at P=0.05 by the least significant difference (LSD) test with aid of the statistical package Stat Graphics 5.1. Diagrams were created by the programme Microsoft Excel XP.

Results and Discussion

In the autumn/winter cultivation, the number of leaves per plant at harvest increased with increasing N application up to 300 mg l^{-1} N irrespective of cultivar, whereas in the spring cultivation leaf number per plant increased significantly when N application rose from 0 to 150 mg l^{-1} but no further at the higher N concentrations (Table 1). In all cases (cultivars and rate of N fertilizer) plants of the spring crop produced more leaves than those of the autumn/winter crop (Table 1). The increase in N concentration also promoted an increase in mean leaf area and leaf fresh weight (Table 1), both of which attained a maximum value at 450 mg l^{-1} in the winter and 300 mg l^{-1} in the spring (except for White Ghiaccio which showed maximum leaf area and weight at 450 mg l^{-1} in the spring crop). The percentage of leaf dry matter showed a reduction with the application of N fertilization, which was not significant in the autumn/winter crop, but statistically significant in the spring crop, in all cultivars. Overall foliar growth was higher in the spring than in the autumn/winter and attained maximum development at a lower N rate. The differences in response of the radish cultivars to N in the two seasons of cultivation are suggested to relate to the climatic conditions that prevailed during the cultivation. The autumn/winter crop is characterized by initially high temperatures (about 20 ^{o}C) that progressively decrease to 7-10 ^{o}C, whereas in the spring temperatures are initially low (7 ^{o}C) but progressively rise to 15 ^{o}C by the end of the crop (Figure 1). During the same periods the mean daily solar radiation varied, in the autumn/winter decreasing from 5.0-6.0 to 2.5-3.0 MJ m^{-2} and in the spring increasing from 5.0 to 9.0-9.5 MJ m^{-2}. Increasing temperature and light irradiation in the spring clearly favour both vegetative and root growth more than the decreasing temperature and solar irradiation experienced during the autumn/winter.

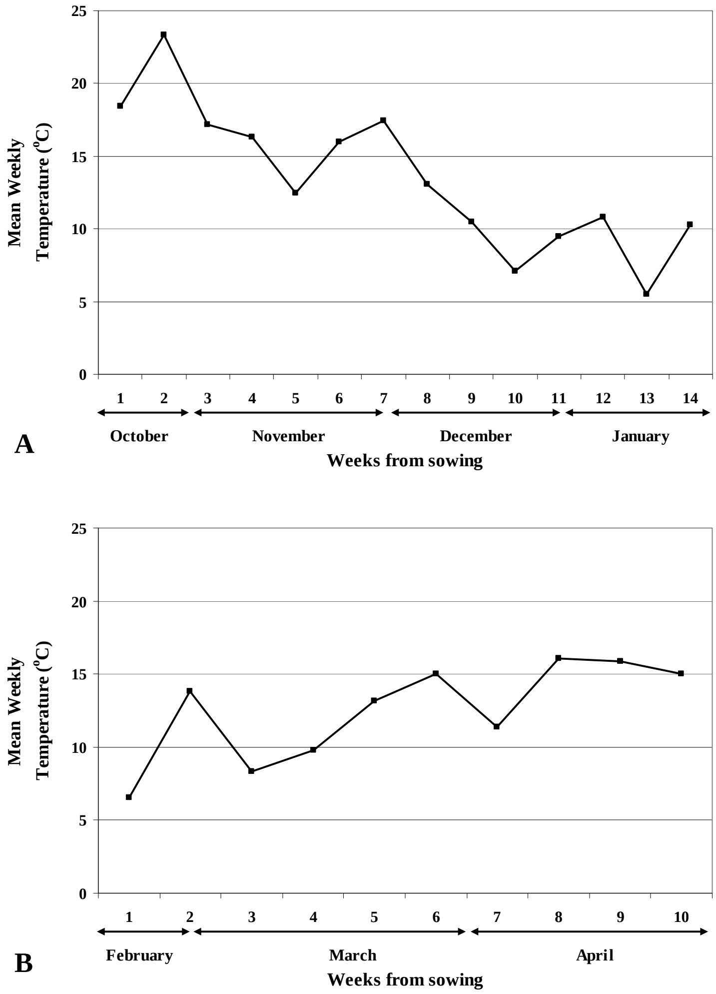

Figure 1. Mean weekly temperatures in the field during the autumn/winter (A) and spring (B) crop.

Table 1. Effect of four rates of nitrogen fertilizer on the number, fresh and dry weight of leaves and leaf area of three radish cultivars cultivated in autumn/winter and spring.

Fertilizer rate	Autumn / Winter						Spring					
	Saxa		Red Fuoko		W. Ghiaccio		Saxa		Red Fuoko		W. Ghiaccio	
	Leaf number plant^{-1}											
0 mg l^{-1} N	4.10	c (ab)*	4.65	c (a)*	3.55	c (b)*	5.90	b (a)*	6.20	b (a)*	6.80	b (a)*
150 mg l^{-1} N	6.30	b (a)*	5.95	b (a)*	4.25	bc (b)*	8.75	a (b)*	10.15	a (ab)*	11.30	a (a)*
300 mg l^{-1} N	6.90	ab (a)*	7.25	a (a)*	5.25	ab (b)*	8.95	a (b)*	11.40	a (ab)*	12.95	a (a)*
450 mg l^{-1} N	7.20	a (a)*	7.75	a (a)*	6.05	a (b)*	9.45	a (b)*	10.00	a (b)*	12.40	a (a)*
	Leaf area plant^{-1}(cm^2)											
0 mg l^{-1} N	62.2	d (b)*	100.6	c (a)	62.3	c (b)*	82.2	c (a)*	106.9	c (a)	102.7	d (a)*
150 mg l^{-1} N	138.9	c (b)*	199.9	b (a)*	88.5	bc (c)*	289.3	b (c)*	598.1	b (a)*	496.8	c (b)*
300 mg l^{-1} N	176.5	b (b)*	245.6	b (a)*	105.7	b (c)*	372.9	a (c)*	791.0	a (a)*	672.4	b (b)*
450 mg l^{-1} N	208.9	a (b)*	317.2	a (a)*	148.5	a (c)*	408.1	a (b)*	754.6	a (a)*	788.6	a (a)*
	Leaf weight plant^{-1} (g)											
0 mg l^{-1} N	2.05	d (c)*	5.06	c (a)*	3.20	c (b)*	4.12	c (c)*	8.68	c (a)*	5.83	d (b)*
150 mg l^{-1} N	5.48	c (b)*	9.26	b (a)*	4.29	c (b)*	15.67	b (c)*	42.56	b (a)*	29.17	c (b)*
300 mg l^{-1} N	7.09	b (b)*	11.75	b (a)*	5.41	b (c)*	22.04	a (c)*	55.92	a (a)*	41.50	b (b)*
450 mg l^{-1} N	9.09	a (b)*	15.87	a (a)*	8.18	a (b)*	22.62	a (c)*	61.69	a (a)*	48.94	a (b)*
	Leaf dry matter (%)											
0 mg l^{-1} N	11.89	a (b)	15.74	a (a)	14.85	a (a)*	11.77	a (b)	14.63	a (a)	11.39	a (b)*
150 mg l^{-1} N	11.49	b (b)*	14.41	a (a)*	14.01	a (ab)*	9.85	b (b)*	11.42	b (a)*	9.38	b (b)*
300 mg l^{-1} N	11.17	b (b)*	14.73	a (a)*	13.76	a (a)*	9.74	b (b)*	11.06	b (a)*	9.46	b (b)*
450 mg l^{-1} N	11.22	b (b)*	14.05	a (a)*	13.92	a (a)*	9.51	b (b)*	10.10	b (a)*	9.57	b (b)*

Means in each column followed by the same letter do not differ significantly at P=0.05.
Means in each row (growing season) followed by the same letter within parenthesis do not differ significantly at P=0.05.
Means in each cultivar and fertilizer rate followed by an asterisk (*) differ significantly at P=0.05.

Previous studies showed that increasing the rate of N fertilization caused only a small increase in the number of leaves per plant, but significantly increased leaf growth, in particular at 150 kg N Ha^{-1} (Guvenc, 2002; El-Desuki et al., 2005). Consequently, in the present study, the plants of the autumn/winter crop responded well to all rates of N fertilization since total N application corresponded to only 33 kg N Ha^{-1} at the rate of 450 mg l^{-1} N, due to the low demand for irrigation at this time of year. In the spring crop, however, where irrigation demand was higher, the application of 450 ppm N (equivalent to or 217 kg N Ha^{-1}) did not promote foliar growth beyond that achieved at 300 ppm N (145 kg N Ha^{-1}).

Root fresh weight increased with increasing N application up to 300 mg l^{-1} (cv. Red Fuoko and White Ghiaccio) or 450 mg l^{-1} (cv. Saxa) in the autumn/winter crop, whereas in the spring crop root fresh weight increased with N application up to 150 mg l^{-1} but not further. Indeed, high N (450 mg l^{-1}) reduced the root weight of cv. White Ghiaccio in both seasons. It is noteworthy that, in contrast to vegetative growth, the effect of the season on root yield was significant only in cv. Saxa (Table 2). Although it is well known that radish responds positively to nitrogen fertilization, the effect of N application up to 200 kg N Ha^{-1} on root yield may either be beneficial (Barker et al., 1983; Guvenc, 2002), or not (Djurovka et al., 1997), but not detrimental. However, in a pot experiment rates up to 310 kg N Ha^{-1} are reported to affect yield negatively, with maximum yield being observed at 270 kg N Ha^{-1} (Liao et al., 2009). In sugar beet (*Beta vulgaris* L. var. *saccharifera* Alef.) cultivated in Greece under semi-arid conditions, root and sugar yield were maximum at high N rates (180-240 kg N/ha), but acceptable at 120 kg N/ha (Tsialtas and Maslaris, 2008).

Table 2. Effect of four rates of nitrogen fertilizer on the fresh and dry weight of the roots of three radish cultivars cultivated in autumn/winter and spring.

Fertilizer rate	Autumn / Winter						Spring					
	Saxa		Red Fuoko		W. Ghiaccio		Saxa		Red Fuoko		W. Ghiaccio	
	Root fresh weight (g)											
0 mg l^{-1} N	7.38	d (c)*	18.88	c (b)*	43.22	d (a)	20.28	b (b)*	13.99	b (c)*	40.46	c (a)
150 mg l^{-1} N	14.64	c (c)*	37.34	b (b)	62.53	c (a)*	39.20	a (b)*	33.87	a (b)	115.61	a (a)*
300 mg l^{-1} N	21.05	b (c)*	50.23	a (b)	80.69	a (a)	45.67	a (b)*	43.21	a (b)	99.43	a (a)
450 mg l^{-1} N	25.78	a (c)*	57.75	a (b)*	70.95	b (a)	41.75	a (b)*	34.10	a (b)*	80.60	b (a)
	Root dry matter (%)											
0 mg l^{-1} N	10.54	a (a)*	9.39	a (b)*	6.52	a (c)*	9.07	a (b)*	12.17	a (a)*	4.94	a (c)*
150 mg l^{-1} N	7.66	b (a)*	7.74	b (a)	5.63	b (b)*	6.06	b (b)*	8.95	b (a)	3.60	c (c)*
300 mg l^{-1} N	6.25	c (a)	7.27	b (b)*	5.09	c (c)*	5.86	b (b)	8.89	b (a)*	4.24	b (c)*
450 mg l^{-1} N	5.82	c (b)	6.80	b (a)	5.12	c (b)	5.78	b (b)	8.40	b (a)	4.36	b (c)

Means in each column followed by the same letter do not differ significantly at P=0.05.
Means in each row (growing season) followed by the same letter within parenthesis do not differ significantly at P=0.05.
Means in each cultivar and fertilizer rate followed by an asterisk (*) differ significantly at P=0.05.

The organoleptic quality of radish is a function not only of root flavour but also of root firmness and crispness. The application of N to levels beyond that present in the control caused a decrease in the percent root dry matter (Table 2) and therefore a reduction in root firmness (Figure 2A). The reduction in dry matter was highest in cv. Saxa (37-45% in spring and autumn/winter) and Red Fuoko (31-38%) at 450 mg l^{-1} N, whereas in cv. White Ghiaccio the corresponding reduction in dry matter was 22% (autumn/winter) and only 9% (not significant) in the spring crop respectively at the same N rate. Even at 150 mg l^{-1} N a significant reduction in the % dry matter content of all cultivars was detected in both seasons. This result indicates that increasing N rates caused a higher water uptake by the roots, which was thus responsible for the increase in root fresh weight, but at the expense of root firmness. Root firmness decreased under the influence of N application in all cultivars. In cv. White Ghiaccio root firmness decreased significantly at as low as 150 mg l^{-1} N, while in Saxa and Red Fuoko firmness fell significantly at 300 mg l^{-1} N and higher (Figure 2A). Irrespective of N level, the loss of firmness represents a serious loss of quality and may enhance sponginess as water is lost during storage. In other experiments (Park and Fritz, 1990), sponginess was related to increased rates of fertilizer application. High rates of N (270 and 310 kg N Ha^{-1}) were also found to decrease the total soluble solids and the ascorbic acid content of roots, thereby impairing root quality (Liao et al., 2009).

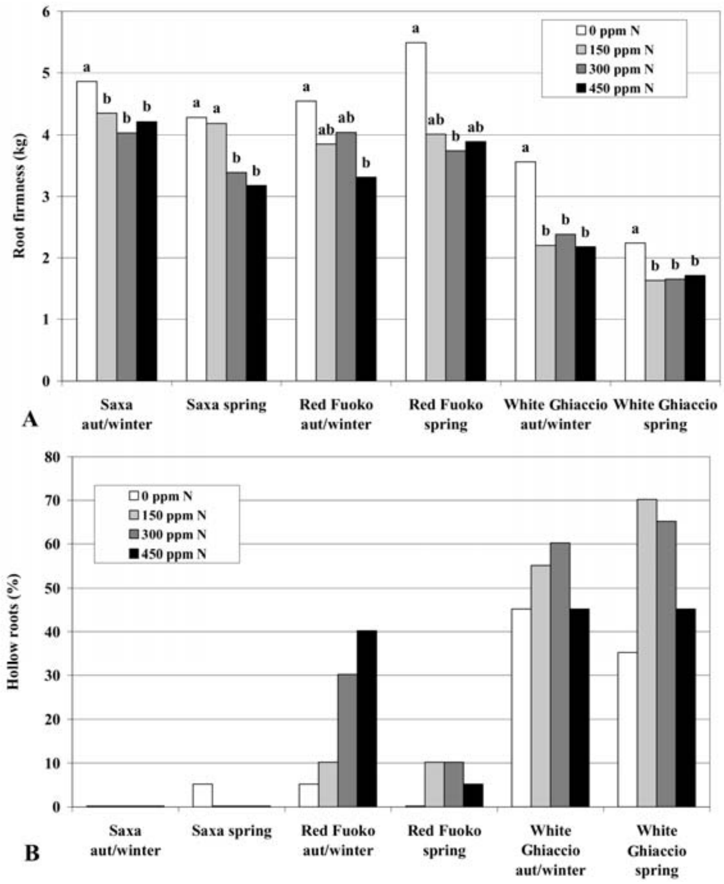

Figure 2. Effect of four rates of nitrogen fertilizer on root firmness (kg) (A) and the percentage of hollow roots (B) of three radish cultivars cultivated in autumn/winter and spring.
Different letters indicate statistically significant differences among N fertilizer rates in each cultivar and season, at P=0.05.

From the data of Figure 2B it may be seen that increasing N application leads to the induction of hollowness in the roots of cv. Red Fuoko, especially in the autumn/winter, whereas in cv. White Ghiaccio this effect was more obvious in the spring. However, with the exception of cv. Red Fuoko in the autumn/winter crop, the application of 450 mg l^{-1} N decreased root hollowness compared to 150 and 300 mg l^{-1} N. The roots of cv. White Ghiaccio irrespective of N fertilization and season, showed a high percentage of hollow roots (more than 40% in most of the cases), followed by cv. Red Fuoko, whereas in cv. Saxa virtually no hollow roots were observed. It may be concluded therefore that hollowness is primarily affected by the cultivar. Radish cultivars producing elongated roots (e.g. daikons-such as White Ghiaccio and Red Fuoko) are more susceptible to sponginess and hollowness than cultivars producing spherical roots, such as cv. Saxa (Hogendonk et al., 1990; Fukuoka and Kano, 1997; Harris et al., 2000). However, rapid elongation of the radish root in response to increased fertilizer application increases the occurrence of hollowness (Fukuoka and Kano, 1997), and this is apparently the case with White Ghiaccio in the spring where increasing N coupled to increasing temperature and solar irradiation (Figure 1) led to rapid root elongation.

In conclusion, a side dressing at a rate of up to 300 mg l^{-1} N can be used to increase radish yield in the autumn/winter and up to 150 mg l^{-1} N in the spring, but this is achieved only at the cost of reducing the percent root dry matter and root firmness, which in turn means a reduction in root quality.

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