Nitrogen requirements at bulb initiation for production of intermediate-day onions

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Abstract

The effect of nitrogen application on growth, nitrogen (N) uptake, yield, and quality of intermediate-day onion (*Allium cepa* 'Guimar') was evaluated in the field in southern Portugal. Plants were fertilized with 30 kg ha^{-1} N at transplanting, 10 kg ha^{-1} N at 29 days after transplanting (DAT) during early leaf growth, and with 0, 20, 40 and 60 kg ha^{-1} N at 51 DAT at the initiation of bulbing. The root system of plants in each treatment were concentrated in the top 0.1 m of soil and limited to 0.3 m depth but neither root length density nor rooting depth were affected by N application during later stages of bulb development. Leaf and bulb dry matter, on the other hand, increased linearly with N rate during bulb growth (85 DAT) and at harvest (114 DAT), respectively. Soil nitrate-N (NO_3-N) at 0-0.3 m depth likewise increased linearly with N rate during bulb growth but declined from 15-30 mg kg^{-1} at bulbing to <10 mg kg^{-1} in each treatment by harvest. A substantial amount of N in the plants, which ranged from 302-525 mg, was taken up from the soil. Application of 60 kg ha^{-1} N resulted in luxury consumption. Yield (fresh bulb weight) increased from 0.19 kg plant^{-1} with no N at bulbing to as much as 0.28 kg plant^{-1} with 60 kg ha^{-1} N. Bulbs harvested from plants fertilized 40-60 kg ha^{-1} N averaged 8.2-8.5 cm in diameter, while those from plants with no N at bulbing averaged only 7.2 cm in diameter. Application of N fertilizer is thus recommended at bulbing to increase N uptake, yield, and bulb size of intermediate-day onions, particularly in dry Mediterranean climates where many onions are produced. Other components of quality, including neck diameter, bulb water content, total soluble solids, and juice pH, were not affect by N applied at bulbing.

Keywords: *Allium cepa*, crop growth, nitrogen uptake, soil nitrate

INTRODUCTION

The correct rate and timing of fertilizer application is essential for maximizing plant nutrient uptake and reducing the risks of nutrient loss. In onion, the potential for nitrogen (N) fertilizer losses due to leaching is high as a result of the crops shallow root system (<0.3 m) and poor lateral root and root hair development (Portas, 1973; Brewster, 1994; Machado et al., 2009). Nitrogen fertiliser recovery is thus often low and typically < 30 to 40%, even when fertilizer application is limited (Brewster, 1994). More than 50% of the N applied annually to commercial onion fields can be lost to leaching (De Visser, 1998).

In Mediterranean climates, including areas in Portugal, Spain, Italy, and California, the risk of groundwater contamination by nitrate (NO_3) leaching from onion production is high because the crop is grown from winter to late spring or early summer when occurrence of rain is relatively high and soil temperatures are favourable to N mineralisation and nitrification. For example, in parts of southern Portugal where onion is produced, NO_3 concentrations reach as much as 10-35 mg L^{-1}. To reduce N loss and increase N use efficiency, N fertilizer is often applied to the crop in split applications throughout the growing season, although more N may be needed at the bulb initiation stage (Halvorson et al., 2002; Machado et al., 2009). Nitrogen uptake is considered to be highest at the initiation of bulb development (Sullivan et al., 2001), and it is at this point that the root system tends to reach the maximum soil depth (Machado et al., 2009).

The objective of the present study was to examine the effects of different rates of N fertilizer application at bulb initiation on N uptake, growth, yield, and quality of intermediate-day onions. We hypothesised that most N applied at bulb initiation would be taken up by the plant and would thus result in the highest gains in yield and bulb quality.

MATERIALS AND METHODS

A field trial was planted on 3 March 2009 at the Mitra Research Farm in Évora, Portugal (38°57' N, 8°32' W; elev. 200 m). Soil at the site was a luvisol sandy loam and in the top 0.4 m at planting had 2.9% organic matter content, a bulk density of 1.48 g cm^{-1}, a pH of 7.2 (1 soil:2.5 water), 13 mg kg^{-1} NO_3-N, >250 mg kg^{-1} P_2O_5 and K_2O, 1520 mg kg^{-1} Ca^{2+}, and 205 mg kg^{-1} Mg^{2+}. The soil samples were analysed by the Agricultural Chemical Laboratory at the University of Évora, which uses a potentiometer for pH, colorimetry for P, flame emission photometry for K, and atomic absorption spectroscopy for Ca for Mg. Three rows of onion seedlings (*Allium cepa* L. 'Guimar') were transplanted at 45 days after emergence into 0.1 m high × 0.6 m wide raised beds at a spacing 0.1 m within rows and 0.2 m between rows and density of 30 plants m^{-2}.

Plants were fertilized with ammonium nitrate (34N-0P-0K) at a rate of 30 kg ha^{-1} N at transplanting, 10 kg ha^{-1} N at 29 days after transplanting (DAT), and with four treatments of 0, 20, 40, or 60 kg ha^{-1} N at 51 DAT at the initiation of bulbing. An additional 7 mg L^{-1} of residual NO_3-N was present (not added) in the irrigation water, which was equivalent to ≈15 kg ha^{-1} N over the season. The N treatments were arranged in a randomised complete block design with four replications per treatment. Each treatment plot was 9 m long and 3 m wide and consisted of three raised beds. No phosphorus or potassium fertilizer was applied.

Irrigation was applied as needed by sprinklers, based on soil water measurements. Soil water tension was measured daily (09:00-10:00 h) using two Watermark soil moisture sensors (Irrometer Co., Riverside, California, USA) installed in each plot at 0.1 and 0.2 m below the soil surface, and irrigation was initiated when readings were ≥25 kPa. The volume of water applied at each irrigation was always less than the sum of potential evapotranspiration (ET_o) from the previous two days; small amounts of water were applied per irrigation to avoid leaching and to provide potential storage space for rain (Enciso et al., 2009). Catch cans (16 cm diameter × 12 cm high) were installed above the crop canopy in the centre of each plot to measure the total amount of rain and irrigation daily.

Soil cores were collected from each plot at 84 and 114 DAT. The cores were 7 cm in diameter taken under the bulb of a randomly selected plant and at 4 cm from the bulb perpendicular to the plant row. Each core was 0.4 m deep and separated into 0.1 m increments. Roots were washed from the cores using a hydropneumatic elutriation root separation system (Smucker et al., 1982), and total root length was measured using a Comair root length scanner (Hawker De Havilland Victoria Ltd., Port Melbourne, Victoria, Australia). Root length density (cm of roots cm^{-3} of soil) was calculated by dividing total root length by the core volume (385 cm^3).

Leaf N and soil NO_3-N were measured at 29, 51, 85, and 114 DAT. On each date, the most recently matured leaves were collected at random from four adjacent plants in each plot and oven-dried at 70°C, ground, and analysed for total N using a combustion analyser (Leco Corp., St. Joseph, MI, USA). Three soil cores were also collected at random between two plants in each plot and analysed for NO_3-N with an ion-specific electrode and meter (Crison Instruments, Barcelona, Spain) using methods outlined by Prazeres (2005). Each core was 3 cm in diameter × 0.3 m deep and was separated into 0.1 m increments. Ammonium-N is quickly converted to NO_3-N under warm, well-aerated, alkaline soil conditions found at the site (Haynes, 1986), and therefore, it was not measured.

For yield and quality evaluation, all of the bulbs from plants grown in the 10 m^2 area were hand-harvested. Equatorial and neck diameters were measured on 100 randomly harvested bulbs per plot, and soluble solids concentration and pH were measured on homogenised juice expressed from six randomly harvested bulbs per plot. Six representative plants were also harvested destructively at 29, 51, 85, and 114 DAT, divided into leaf and bulb components, oven-dried at 70°C for 2-3 days, and weighed. Soluble solids (°Brix) and pH were measured in homogenized onion juice of the six bulbs.

Data were analysed by analysis of variance using SPSS software (Chicago, Illinois, USA), and means were separated at a 5% level using Fisher's protected least significant difference (LSD) test. Response to N rate was determined using trend analysis.

RESULTS AND DISCUSSION

Soil nitrate

Soil NO_3-N increased linearly with N rate and soil depth at 85 and 114 DAT, indicating that N applied at the higher rates was perhaps excessive and not totally taken up by the plants (Table 1). On average, values at 0-0.3 m depth decreased from 22 mg kg^{-1} at bulbing (data not shown) to 7 mg kg^{-1} at harvest (114 DAT). This decrease occurred mostly between 51 and 85 DAT and primarily in the top 0.2 m of the soil profile, where most of the root system was concentrated (see below).

Table 1. Effects of N fertilizer rate and sample depth on soil NO_3-N levels in a field of 'Guimar' onion at 85 and 114 days after transplanting (DAT).

Source of variation[1]	Soil NO_3-N (mg kg^{-1})	
	85 DAT	114 DAT
N rate (kg ha^{-1})[2]		
0	9 b[3]	5 b
20	11 b	6 ab
40	11 b	7 ab
60	16 a	8 a
Significance	L**	L*
Depth (m)		
0-0.1	10 b	6 b
0.1-0.2	12 ab	6 b
0.2-0.3	14 a	8 a
Significance	L**	L**

[1]There was no significant interaction between N rate and depth on either date.

[2]The fertilizer was applied at bulbing. Each treatment was also fertilized with 30 kg ha^{-1} N at planting and 10 kg ha^{-1} N at 29 DAT plus ≈15 kg ha^{-1} N over the season from residual NO_3-N (7 mg L^{-1}) in the irrigation water.

[3]Means followed by different letters in a column are significantly different at $P \leq 0.05$.

*, ** Significant for linear (L) effects at $P \leq 0.05$ and 0.01, respectively.

Root development

Nitrogen application had no effect on root length density or maximum rooting depth at 84 and 114 DAT, either under the bulb or at 4 cm from the plant (Figure 1). Machado et al. (2009) likewise found little difference in rooting when N was applied at different rates over the growing season. Melo (2003), however, found that root length density at 60 DAT decreased with reduction of available soil N. Root length density was similar to values observed in other root studies on onion (Portas, 1973; Thourp-Kristensen, 2001; Machado and Oliveira, 2008). Approximately 97% of the total root length measured under the bulbs was concentrated in the top 0.2 m of soil (data not show), which is similar to the 90% found by Brewster (1994).

Leaf and bulb dry weights

Nitrogen rate significantly affected leaf dry weight at 85 DAT and bulb dry weight at 114 DAT (harvest) (Table 2). Most of the plant dry matter was partitioned to the bulb during the final stage of bulb development (i.e., 85-114 DAT), which was consistent with a previous report by Tei et al. (1996). By harvest, approximately 65% to 74% of total aboveground biomass was allocated belowground to the bulbs. Pôrto et al. (2006) observed similar values, while Sullivan et al. (2001) and Pire et al. (2001) reported values as high as 85 and 97%, respectively.

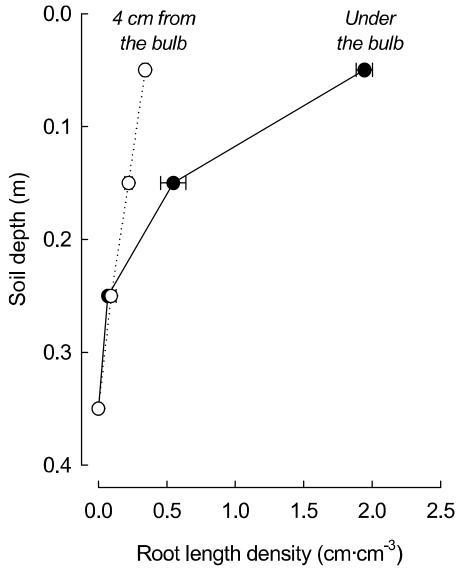

Figure 1. Root distribution of 'Guimar' onion grown in sandy loam soil in Évora, Portugal. Each symbol represents the mean of four replicates averaged over four nitrogen rates (0, 20, 40 and 60 kg ha^{-1} N applied at bulbing) and two sampling dates (85 and 114 days after transplanting) and error bars represent ±1 SE.

Table 2. Effects of different N rates on leaf and bulb dry weight of 'Guimar' onion at 85 and 114 days after transplanting (DAT).

N rate (kg ha^{-1})[1]	Leaf dry wt (g plant^{-1}) 85 DAT	Leaf dry wt (g plant^{-1}) 114 DAT	Bulb dry wt (g plant^{-1}) 85 DAT	Bulb dry wt (g plant^{-1}) 114 DAT
0	10.4 b[2]	8.5	8.9	20.8 b
20	14.8 ab	7.9	9.9	22.6 ab
40	15.0 ab	10.6	10.4	21.7 ab
60	17.0 a	12.2	10.9	23.2 a
Significance	L**	NS	NS	L*

[1]The fertilizer was applied at bulbing. Each treatment was also fertilized with 30 kg ha^{-1} N at planting and 10 kg ha^{-1} N at 29 DAT plus ≈15 kg ha^{-1} N over the season from residual NO_3-N (7 mg L^{-1}) in the irrigation water.

[2]Means followed by different letters in a column are significantly different at $P \leq 0.05$.

NS, *, ** Non-significant and significant for linear (L) effects at $P \leq 0.05$ and 0.01, respectively.

Leaf and bulb N concentrations

Leaf N concentrations were lower at both 85 and 114 DAT with no N than with 60 kg ha^{-1} N applied at bulbing (Table 3). Leaf N ranged from an average of 15.1-18.0 g kg^{-1} with 0 kg ha^{-1} N and from 20.2-20.8 g kg^{-1} with 60 kg ha^{-1} N. These levels were similar to those reported for sweet onion in Florida (Hochmuth et al., 1991) but lower than the levels recommended by others at this stage of development [Maynard and Hochmuth (1997) and University of California Cooperative Extension (2011) recommend >25 g kg^{-1}, while Mills and Jones (1996) recommend levels as high as 45-50 g kg^{-1}]. Tissue N concentrations are often affected by cultivation practices, soil type, and climate and, therefore, often differ among studies and growing areas (Westerveld et al., 2003).

Nitrogen uptake

Nitrogen uptake in the plants increased with N rate at 85 and 114 DAT but only when 60 kg ha^{-1} N was applied (Table 3). Shoot N uptake ranged from 302-525 mg $plant^{-1}$. Nitrogen uptake in the leaves and bulb totalled 91, 101, 108, and 157 kg ha^{-1} in the increasing N treatments, respectively. Given that the total amount of N applied to each treatment equalled only 55, 75, 95 and 115 kg ha^{-1}, at least 12.7-42.4% taken up in the leaf and bulbs apparently came from mineralization and soil N available prior to pre-plant. Conditions for mineralisation likely improved after bulbing due to an increase in soil temperature (data not shown).

Table 3. Effects of different N rates on leaf and bulb N concentrations and total (leaf + bulb) N uptake of 'Guimar' onion at 85 and 114 days after transplanting (DAT).

N rate	Leaf N (g kg^{-1})		Bulb N (g kg^{-1})		N uptake (mg $plant^{-1}$)	
(kg ha^{-1})[1]	85 DAT	114 DAT	85 DAT	114 DAT	85 DAT	114 DAT
0	15.1 b[2]	18.0 b	5.6	7.1 b	214 b	302 b
20	18.0 ab	18.5 ab	6.5	8.4 b	331 ab	336 b
40	18.9 ab	18.8 ab	6.2	7.4 b	339 ab	359 b
60	20.8 a	20.2 a	9.0	12.1 a	450 a	524 a
Significance	Q**	Q**	NS	Q**	L**	Q**

[1]The fertilizer was applied at bulbing. Each treatment was also fertilized with 30 kg ha^{-1} N at planting and 10 kg ha^{-1} N at 29 DAT plus ≈15 kg ha^{-1} N over the season from residual NO_3-N (7 mg L^{-1}) in the irrigation water.

[2]Means followed by different letters in a column are significantly different at $P \leq 0.05$.

NS, *, ** Non-significant and significant for linear (L) or quadratic (Q) effects at $P \leq 0.05$ and 0.01, respectively.

When N fertilizer was applied, ≈68% of total N uptake occurred between 51 and 85 DAT, averaging 6.7-10 mg $plant^{-1}$ day^{-1}. Nitrogen uptake was much lower early in the season (0-29 DAT) when shoot growth was low and late in the season as the bulbs matured (85-114 DAT). During later stages of bulb development, N is translocated from leaves to the bulb (Sullivan et al., 1999; Nasreen and Hossain, 2004). Therefore, most N should be applied between one month after planting and bulb initiation.

Yield and bulb quality

Yield increased linearly with N application at bulbing ($P \leq 0.01$) (Figure 2). Commercial yield was high and averaged 5.6-7.8 kg m^{-2} with 0-40 kg ha^{-1} N. Additional N resulted in little additional yield and likely resulted in luxury consumption.

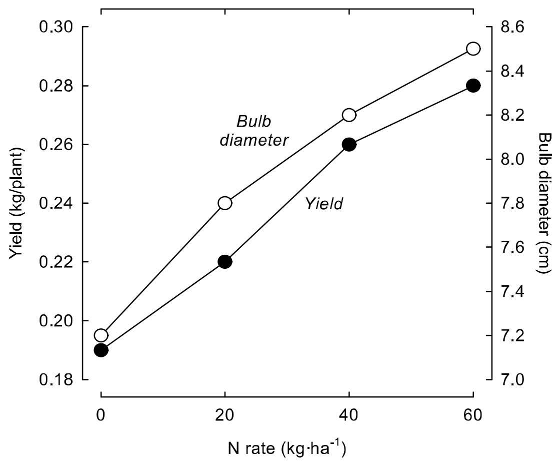

Figure 2. Effects of N fertilizer rate (at bulbing) on yield and bulb diameter in 'Guimar' onion. Each symbol represents the mean of four replicates averaged over four nitrogen rates (0, 20, 40 and 60 kg ha^{-1} N applied at bulbing).

Nitrogen applied at bulbing also increased bulb diameter linearly ($P \leq 0.01$) (Figure 2) but had no effect on neck diameter of the bulb or soluble solids concentration and pH of the bulb juice (data not shown). Onions fertilized at bulbing averaged "jumbo" in size (7.5-10 cm diameter) and included 10% in the "colossal" size category (>10 cm), whereas those grown without N fertilizer at bulbing averaged only "medium" in size (6-7.5 cm) and were no larger than 9 cm in diameter. Thus, there is an additional incentive to apply at least some N at bulbing as premium prices are paid for larger onions. Total soluble solids concentration and pH of the onions differed little among N treatments and averaged 8.4 and 5.5%, respectively; both of these values are considered "normal" for onion (Rodríguez Galdón et al., 2008). Quality of the onion bulbs was also found to be unaffected by N fertilizer by others, including studies where various amounts of N were applied at planting (Biesiada and Kolota, 2009; Machado et al., 2009) or where total rates were as high as 590 kg ha^{-1} N (Maier et al., 1990; Randle, 2000).

CONCLUSIONS

Application of N fertilizer at bulbing increased yield and bulb size in intermediate-day onion in southern Portugal. In addition to 30 kg ha^{-1} N applied at planting, 10 kg ha^{-1} N applied at 29 DAT, and ≈15 kg ha^{-1} N from residual NO_3-N (7 mg L^{-1}) in the irrigation water, at least 40 kg ha^{-1} N was required at bulbing to maximize yield in the planting. The additional N fertilizer applied at bulbing also increased bulb size but had no effect on other measures of quality, including soluble solids and juice pH.

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