Commercial Yield and Quality of Fruits of Cucumber Plants Cultivated under Greenhouse Conditions: Response to Increases in Nitrogen Fertilization

Juan Manuel Ruiz* and Luis Romero

Department of Plant Biology, Faculty of Sciences, University of Granada, E-18071 Granada, Spain

Rates of nitrogen application were studied in relation to commercial yield and fruit quality of cucumber plants (*Cucumis sativus* L. cv. Bunex). All plants were grown under controlled conditions in a greenhouse. Treatments consisted of the application of N as KNO_3 (N1, 2.5 g m^{-2}; N2, 5 g m^{-2}; N3, 10 g m^{-2}; N4, 20 g m^{-2}; and N5, 40 g m^{-2}). The fruits of cucumber from the N3 and N4 treatments were best for human consumption and economic profit. These N application rates encouraged a good relationship between commercial yield and fruit quality. The N5 rate resulted in low commercial production and low quality; the fruit had the greatest NO_3^- and the least Ca concentrations, which diminished firmness of the fruit. Finally, the N1 and N2 rates produced poor yield and poor commercial quality.

INTRODUCTION

Appropriate levels of NO_3^- -N in plant derived from proper N fertilization boost the amount and activity of nitrate reductase (NR), and this in turn increases the potential for NO_3^- reduction, conferring a greater capacity for amino acid synthesis, protein synthesis, or total N assimilation (Sivasankar and Oaks, 1996). Plant growth rate and yield are often dependent on N supply (Mattson et al., 1991; McDonald et al., 1996; López-Cantarero et al., 1997), although excess N often results in poor fruit quality and depresses commercial yield (Davenport, 1996; López-Cantarero et al., 1997).

In relation to fruit quality, cucumber plants grown under greenhouse conditions with N fertilization have received little attention. In other crops, reports are contradictory concerning the effects of N on some of the parameters that define fruit quality (firmness, Ca, organic acids, pH, soluble solid compounds (SSC), and sugars) with some authors finding positive effects (Cummings and Reeves, 1971; Raese and Drake, 1997) and other negative effects (Beutel, 1988). Still other works found fruit quality unaffected by N additions (Schultheis and Dufault, 1994; Alleyne and Clark, 1997; Miner et al., 1997).

Taking into account that the massive use of N contributes to groundwater and surface-water pollution through leaching and soil erosion (Sisson et al., 1991), and bearing in mind the widespread economic importance of the cucumber, our aim was to evaluate the effect of N fertilization (NO_3^--N) on the yield and quality of the commercial fruits of the cucumber plant.

MATERIALS AND METHODS

Crop Design. *Cucumis sativus* L. cv. Bunex were seeded in cell flats (cell size $3 \times 3 \times 10$ cm) filled with peat-lite mixture and placed on benches under the greenhouse conditions described below, for a period of 8 weeks; then seedlings were transplanted and grown under controlled conditions in an experimental greenhouse at Centro de Investigación y Desarrollo Hortícola, El Ejido, Almería, Spain. The greenhouse experiment began in October 1996 and ended in February 1997. The climate is semiarid, and the lands are intensively used for agriculture. The soil used was loamy-sand with the following characteristics: sand (37.3%), silt (48.6%), clay (10.1%), $CaCO_3$ equivalent (26.82%), $CaCO_3$ active (14.35%), total N (3.5 g kg^{-1}), total organic C (36.1 g kg^{-1}), PO_4^{-3} (890 mg kg^{-1}), K^+ (5.34 g kg^{-1}), pH (H_2O, 8.45; KCl, 8.01), electrical conductivity (EC = 4.63 dS m^{-1}). The relative humidity was 60–80%, and the temperature range was 24 ± 4 °C with extremes of 15 and 30 °C in the greenhouse. The experimental design was a factorial arrangement in a randomized complete block with five treatments. Each treatment was replicated three times in three individual plots of 4 m × 2 m wide (15 plots). Each plot contained eight treated plants. The irrigation water had the following properties: pH, 8.05; EC, 2.03 dS m^{-1}; Cl^-, 483.90 mg L^{-1}; Na^+, 305.76 mg L^{-1}; K^+, 10.16 mg L^{-1}; HCO, 278.15 mg L^{-1}.

The different treatments consisted of applying increasing rates of N in the form of KNO_3 (N1, 2.5 g m^{-2}; N2, 5 g m^{-2}; N3, 10 g m^{-2}; N4, 20 g m^{-2}; and N5, 40 g m^{-2}). P was supplied in the form of H_3PO_4 (15 g m^{-2}). Calcium (11 g m^{-2}) and magnesium (3 g m^{-2}) were supplied as sulfates. The rate of each nutrient was applied gradually with the irrigation water over the entire growth period of the plants. Fertilization–irrigation was complemented with the following micronutrients: Fe, 0.5 mg L^{-1}; B, 0.1 mg L^{-1}; Mn, 0.1 mg L^{-1}; Zn, 0.075 mg L^{-1}; Cu, 0.075 mg L^{-1}; and Mo, 0.05 mg L^{-1}. The pH values of the solution oscillated between 5 and 6; Fe was applied as FeEDDHA, B as H_3BO_3, and the remaining micronutrients as sulfates.

Fruit Sampling and Analysis. Cucumbers were usually harvested at maturity. Commercial yield was determined by weighing only marketable fruits on each plant. The term "marketable", or "commercial", signifies fruit with acceptable color, caliber, and firmness.

In each treatment, 30 representative marketable fruits were sampled (10 fruits/replicate) for analysis. Soluble solids compounds (SSC) of a composite juice sample were measured with a hand-held refractometer (Belakbir et al., 1998). Ten grams of fresh fruit was crushed in a mortar, and the extract was assayed for citric acid by titration with 0.1 N NaOH (Belakbir et al., 1998). Ascorbic acid concentration was analyzed according to the Association of Official Analytical

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Table 1. Effect of Applied N Rate on Commercial Yield, Water Content, and Accumulation of Various N Compounds in Cucumber Fruits[a]

	commercial yield, kg fw Ha^{-1}	water content, %	amino acids, mg g^{-1} fw	proteins, mg g^{-1} fw	nitrate, mg g^{-1} dw	organic N, mg g^{-1} dw
N1	13700 ± 690e	96.3 ± 1.53a	0.26 ± 0.03d	2.81 ± 0.31d	0.46 ± 0.06e	19.2 ± 2.21c
N2	16600 ± 740d	96.0 ± 1.42a	0.45 ± 0.05c	3.48 ± 0.33c	0.77 ± 0.09d	21.7 ± 2.33c
N3	27300 ± 790b	95.1 ± 1.52ab	0.58 ± 0.04c	3.67 ± 0.35c	1.12 ± 0.11c	23.4 ± 2.29bc
N4	31100 ± 860a	93.3 ± 1.35b	0.84 ± 0.07b	3.94 ± 0.41b	1.67 ± 0.13b	25.8 ± 2.43b
N5	21900 ± 760c	90.1 ± 1.39c	1.09 ± 0.08a	4.38 ± 0.39a	2.17 ± 0.16a	29.2 ± 2.51a

[a] Values followed by the same letter within a column were not measurably different ($p < 0.05$). Data are means ± SE ($n = 3$).

Table 2. Effect of N Application Rate on Cucumber Fruit Quality[a]

	total Ca, mg g^{-1} dw	ascorbic acid, mg kg^{-1} fw	citric acid, mg kg^{-1} fw	SSC, %	glucose, mg g^{-1} fw	frutose, mg g^{-1} fw	sucrose, mg g^{-1} fw
N1	7.37 ± 0.51a	10.1 ± 0.27b	5.21 ± 0.23b	2.18 ± 0.17e	31.8 ± 3.41b	38.2 ± 4.73b	29.3 ± 2.95b
N2	6.93 ± 0.66a	11.4 ± 0.29b	6.13 ± 0.24b	2.78 ± 0.19d	32.2 ± 3.62b	38.7 ± 4.83b	29.7 ± 2.46b
N3	6.82 ± 0.48ab	13.7 ± 0.31ab	8.46 ± 0.26ab	3.69 ± 0.23c	35.0 ± 3.77a	42.0 ± 4.99a	32.2 ± 3.12a
N4	6.73 ± 0.51ab	14.1 ± 0.30a	9.04 ± 0.25a	3.99 ± 0.18b	35.0 ± 4.01a	42.0 ± 5.23a	32.2 ± 3.07a
N5	5.04 ± 0.44b	14.5 ± 0.33a	9.82 ± 0.26a	4.32 ± 0.21a	35.3 ± 3.89a	42.4 ± 5.12a	32.5 ± 3.18a

[a] Values followed by the same letter within a column were not measurably different ($p < 0.05$). Data are means ± SE ($n = 3$).

Chemists (1984) colorimetric method. Amino acids and soluble proteins in fruits were determinated as described by Yemm and Cocking (1955) and Bradford (1976), respectively, and finally the soluble carbohydrates (glucose, fructose, and sucrose) were measured following the method of Irigoyen et al. (1992).

For the determination of total Ca and organic N, fruits were washed with a 1% soap solution and then rinsed three times with distilled water. Samples were dried in a forced air oven at 70 °C for 48 h and ground to pass a 20-mesh screen in a Wiley mill. Dried material was digested with H_2SO_4 and H_2O_2 (Wolf, 1982). The total Ca concentration was measured by atomic absorption spectrophotometry (Hocking and Pate, 1977), and organic N was measured by spectrophotometry method (Baethgen and Alley, 1989). Finally, NO_3^- was analyzed from an aqueous extraction of dried and ground fruit material (Cataldo et al., 1975).

Statistical Analysis. The data shown are mean values ± error standard (SE). Analysis of variance (ANOVA) was used to evaluate treatment means, which were compared using least significant difference at the 0.05 probability level. Means were tested using Duncan's multiple range test.

RESULTS AND DISCUSSION

The effect of N fertilization on commercial yield (Table 1) was greatest at the N4 application rate and least at the N1 rate. In general, the greater yield at greater N application rates confirmed previous claims that commercial yield depends on the N application rate (Mattson et al., 1991; López-Cantarero et al., 1997). Nevertheless, in the maximum N treatment (N5), yield fell by 30% (Table 1). Evidence indicates that excess N can encourage excess vegetative production and simultaneously reduce crop yield (Davenport, 1996). In addition, López-Cantarero et al. (1997) demonstrated that increased N fertilization augmented noncommercial production at the expense of commercial yield.

The water content of the fruits was noticeably affected by the N treatments (Table 1), with N1 giving rise to the greatest percent water content and N5 the least. The water content at N5 probably is consistent with the fact that the greatest amount of dry matter was also produced at this application rate.

Nitrate is studied by the World Health Organization (WHO) as one of the compounds detrimental to human health when present in food at high concentrations (3.5−4.5 mg g^{-1} fw) (Van der Boon et al., 1990; Weigert et al., 1997). In our experiment, the highest NO_3^-

concentrations were found at the N5 application rate (Table 1). In relation to the nitrogenous compounds, the results show that amino acids, proteins, and organic N increased with N rate (Table 1). This fact could signify an increase in the synthesis of dry matter in the fruits treated with N5, leading in many cases to deformations in the fruits, thereby diminishing the commercial yield.

Table 2 presents other parameters which reflect fruit quality. The role of Ca in the maintenance of the firmness of the fruits is well-known. The requirements of Ca in fruit are related to cell-wall stability and membrane integrity (Belakbir et al., 1998). The effects described of N on Ca in general, and on fruit firmness in particular, have been contradictory, receiving both positive (Miner et al., 1997) and negative reports (Olienyk et al., 1997). Here, increased N fertilization decreased the Ca concentrations, the least Ca concentration being recorded for the N5 rate (Table 2). It should be taken into account that in our experiment, N was applied together with K, and therefore the maximum K application in N5 possibly diminished Ca uptake, given the antagonistic relationship between these two nutrients (Song and Fujiyama, 1996). The reduction in Ca, and therefore firmness, at the N5 rate appears to account for the reduction in commercial yield, as firmness is one of the definitive parameters in fruit quality (Belakbir et al., 1998).

Organic acids (ascorbic acid and citric acid; Table 2) were strong determinants of fruit acidity (Akl et al., 1995). We found no statistical differences between the results in the N3, N4, and N5 treatments, and thus these parameters were unaffected by the highest N application rates.

Therefore, the higher N application rates raised the SSC level, which is a parameter determinant of fruit quality (Schultheis and Dufault, 1994; Raese and Drake, 1997; Alleyne and Clark, 1997; Belakbir et al., 1998), and the greatest content occurred with the N5 rate (Table 2).

Finally, the soluble sugars (glucose, fructose, and sucrose), like the SSC, are important parameters in the evaluation and quality of the fruits (Ho, 1996). The greatest concentrations of soluble sugars were found with N5 (Table 2), perhaps due to an accelerated rate of respiration caused by intensive fruit growth (Tazuke

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and Sakiyama, 1991). The N quantity or availability to the plant largely determines its growth and yield. The N5 treatment possibly resulted in enhanced growth and dry-weight production in the fruits (Mattson et al., 1991; McDonald et al., 1996), thereby lowering the water content (Table 1) and raising the SSC and soluble sugar contents (Table 2) (Raese and Drake, 1997).

In conclusion, taking into account the crop and growth conditions chosen, cucumber fruits treated at the N3 and especially N4 application rates would be most advisable for both human consumption and agricultural profitability, as these rates resulted in the best commercial yield and fruit quality. The N1 and N2 rates would not be advisable because of their low commercial yield, and N5 treatment would not be recommended because of the poor low commercial yield and poor fruit quality (both firmness and nitrate content). Finally, we should emphasize that the N was applied jointly with the K, thereby perhaps influencing both commercial yield and fruit quality, given that the more extensively studied N has been deemed more determinant, although K is also involved in these processes (Satti and Lopez, 1994; Lopez and Satti, 1996; Johnson and Decotean, 1996).

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