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Nitrogen/Ammonium Concentration Response of Vegetable and Flower Crops

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Abstract: Nitrogen (N) is the element with the greatest influence on the growth of vegetables and ornamentals, however, form of delivery, either as nitrate (NO_3^-) or ammonium (NH_4^+) has different effects on plant development. The NO_3^- is the main form of N that plants absorb, but when it is the only source of N that has slight effects on root growth, no effects over enzymatic activities, and stimulates the absorption and translocation of cations within the plant. The NH_4^+ is the easiest way of assimilation but is highly toxic when the only source or with respect to the concentration of NO_3^- is too high. To avoid toxicity, the NH_4^+ must not exceed 20% of the total N amount in the formulation, however, it is important to consider the species, variety and environmental conditions. The N as supplied also affects the resistance or susceptibility of plants to diseases, but depends on the species and the type of pathogen.

Key words: Nitrate, ammonium, vegetables, ornamental, toxicity, nutrition.

1. Introduction

The development of plants is affected by internal and external factors. Some external factors are essential elements, if these are not available or in low concentration, the plants show deficiency symptoms [1]. However, nitrogen (N) is the element required in large amounts by plants, which has the greatest influence on growth [2]. The main forms of N supplied to roots are nitrate (NO_3^-) and ammonium (NH_4^+) [3], which affect the growth, morphology and the nutrient status [4]. Most of plant prefers NO_3^- because high concentration of NH_4^+ is toxic for its metabolism [5]. However, the addition of an optimum rate of NH_4^+ to a NO_3^--N containing nutrient solution maximizes absorption and promotes the growth in plants, when growth conditions are favorable [6, 7], furthermore, affects the response of plants to diseases. The objective of the present review is to delineate the effect of the form on which nitrogen is supplemented on plant growth, development, nutrient status in ornamental and tolerance to diseases and horticultural species.

2. Importance of Nitrogen in Floriculture and Vegetable Plants

N is a mineral nutrient required in large quantities and their availability is an important factor for normal growth and development of plants [8]. Vegetable production requires large quantities of this element [9], because it is a constituent of protein, many related metabolites synthesis and energy transfer and nucleic acids [10], therefore plays an important role in the quality of crops [11].

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2.1 Forms of Nitrogen Supply to Plants

The N can be supplied to plants in form of NO_3^- and NH_4^+ [12]. The NO_3^- is absorbed preferentially by the majority of plants, making it the most widely used [13]. The NH_4^+, at certain concentrations, can be toxic to many of them [14] and generally recommended for application in small amounts after transplantation. Furthermore, the N form influences the growth, yield and chemical composition of the plant tissues [15]. Absorption of NO_3^- and NH_4^+ varies according to the species, strain, temperature, pH and light intensity, as can be found in various crops [10]. The N supply form has effect on photosynthesis, stomatal conductance and intercellular carbon dioxide (CO_2), but the results are not consistent among different plant species [16].

2.2 Ammonium Effect on Plants

The NH_4^+ is the inorganic form of N assimilation, since nitrates and nitrites must be first reduced to NH_4^+ [17]. According to Britto and Kronzucker [18], if the NH_4^+ is the only N source, it generally has harmful effects on the growth of plants and may result in symptoms of toxicity in many of them; according to Simonne et al. [19], this is due to irreversible alteration of the structure of the thylakoid membrane. Furthermore, the plant response to continuous nutrition with NH_4^+ depends on the species. For example, spinach is sensitive, sunflower is moderate, and however, the pea is tolerant to high doses of NH_4^+ [20]. To avoid toxicity, NH_4^+ should not exceed 20% of the total amount of N in the formulation [10]. When cucumber plants were grown in a constant concentration of 5 mM NH_4^+ its growth decreased, meaning that it is a sensitive species [21]. In potato, N uptake in the initial phase of development was in the form of NH_4^+, after 56 d (tuber formation) was as NO_3^- [10]. With 1.5 mM of NH_4^+ in the nutrient solution, vigorous pepper seedlings were obtained and more nutrient uptake [22]. NH_4^+ accumulation correlates with an increased content of organic N [20]. The addition of NH_4^+ to nutrient solutions formulated with NO_3^- allows to increase the N absorption rate in rose plants in hydroponics during stem elongation; same behaviour shows the K absorption, whereas the P concentration increased only in the roots of plants [23]. However, the absorption and accumulation of excess NH_4^+ can cause toxicity and low concentration of Ca and Mg in the tissue of tomato plants [7]. The use of ammonium sulfate [$(NH_4)_2SO_4$] in the onion growth increased the yield of onion bulb when the amount of application of fertilizer was increased (0, 250 and 500 kg/ha), also significant changes in the composition of the pectin in the bulbs during storage were observed [24]. Moreover, the effect of concentration of NH_4^+ in two chrysanthemum growths (Mountain Snow and Feast) was evaluated using a Steiner nutrient solution (51.7 mg/L NO_3^- and 0 mg/L to 500 mg/L of NH_4^+). The cv. Mountain Snow was sensitive to drought and toxicity of NH_4^+ (180 mg /L); it also showed lower concentrations of Ca, K and Zn on the lower leaves. The cv. Feast was resistant to drought, it also showed increment of chlorosis, slower growth rate and lower production of dry matter. Although the concentration of calcium in the leaf tissue was also significantly reduced by the toxicity of NH_4^+, concentrations of Mg, Mn, Fe and Zn were not affected. The tolerance to NH_4^+ in the cv. Feast could be associated with a longer time to maintain the root functions and nutrient absorption in presence of NH_4^+ [25]. Meanwhile, vegetative and reproductive growth of eggplants can be manipulated without damage by supplying N based on NH_4^+, as long as the age of the plants, the carbohydrate from the roots, the amount of NH_4^+ supplied, and the pH of the growth medium are favourable [26]. In Anturio, growth is affected when using a NH_4^+ fraction as a source of N, as the results show that the increase of this ion in the nutrient solution until at least a third of the total N improved growth, development and plant performance [27], but more research is suggested to find the best value for $NO_3^-:NH_4^+$.

2.3 Nitrate Effect on Plants

The NO_3^- affects slightly the growth of plant roots when only is the source of N [28].

In cultivation of strawberry cv. Osogrande, produced in hydroponic system using three NO_3^- concentrations (3.75, 7.5 and 15 mM/L) was observed a linear behaviour between the solution concentration and NO_3^- concentration in strawberry tissue. The concentration of NO_3^- in the nutrient solution did not affect the activity of nitrate reductase (NR) in leaves and roots during the vegetative and reproductive stages. The average of NR activity in leaves in both stages was 360 nM/g fresh weight (FW)/h NO_2. In roots was 115 nM/g FW/h NO_2 [29]. The data suggest that the lack of response of strawberry to increased NO_3^- to increase the growth and fruit yield is due to limitations in the reduction or assimilation of this compound both in root and leaves, rather than rates absorption. On the other hand, cv. Aromas was produced in a hydroponics system using N as $Ca(NO_3)_2$ at concentrations of 0.3, 3 and 6 mM/L in the nutrient solution. The fruits were produced with higher content of esters, soluble carbohydrates and amino acids to 3 mM/L and 6 mM/L concentrations. The bigger concentration of Hexanal was obtained using 6 mM/L concentration. The fertilization effect was more marked in the second harvest date [30]. The tomato plant is suggested to increase the NO_3^- concentration as it stimulates the absorption and translocation of cations. These requirements are necessary to transport the NO_3^- ions to upper parts of the plants (the main site of NO_3^- reduction) [31].

2.4 Nitrate/Ammonium Concentration Effect over Plants

Nutrition of strawberry cv. Seolhyang in semi-hydroponics with a ratio of NH_4^+:NO_3^- (40:60) had effects on yield, growth and nutrient uptake [32]. The yield increased by 38% and 84% of strawberry cv. Camarosa and Selva, respectively, when plants were fertilized with 25:75 of NH_4^+:NO_3^- compared with plants in a solution of higher proportion of NH_4^+. The positive result is due to fruit size observed, i.e., length and fresh weight of the fruits. Moreover, the higher net photosynthetic rate obtained could benefit the plant growth, yield and quality of fruit [15]. The cv. Selva showed higher NR activity during vegetative stage due to NO_3^-/NH_4^+ relationship. The maximum activity occurred at 6:1 mM/L (NO_3^-/NH_4^+). They also had higher nitrogen content in this ratio compared with the ratio 7:0 mM/L (NO_3^-:NH_4^+). In general, the cutter needs more N as NO_3^- to NH_4^+ in the vegetative stage, but the NH_4^+ should not exceed more than 50% of total N in the nutrient solution. The stages of plant development and environmental conditions determine the best value for NO_3^-:NH_4^+ [33]. By raising the supply of NO_3^- from 10.5 meq/L to 13.5 meq/L in combination with a high ratio of NH_4^+ in the cultivation of chrysanthemum, the concentration of K^+, Mg^{2+} and Mn^{2+} have increased significantly in leaves. Jeong and Lee [34] reported that the ratio 85:15 of NO_3^-:NH_4^+ in chilli seedlings had better growth.

3. Nitrogen Role in the Defence Mechanism against Diseases

The N plays a role in the relationship between nutrients, plants and pathogens [35]. Excess of nitrogen fertilizer in plants has effect on developing and growing (vegetative growing and higher water content). This internal condition of the plant can attract insects, especially sucking and chewing, which are potential disease vectors [36]. The form of N supply also influences the development of some pathogens. This was observed in tomato plants which were given different ratios NH_4^+:NO_3^- (0:100, 50:50 and 100:0) and whose seedlings were infected with root knot nematode *Meloidogyne javanica*. At the time of evaluation after 30 d and 60 d after inoculation, the nematodes showed no impairment in their development. The male population of *Meloidogyne javanica* increased when the tomato was nurtured with 100% NH_4^+. The male population of *Meloidogyne* *javanica* increased in tomato fertilizer with 100% NH_4^+, however, its roots had greater strength when nurtured with NO_3^- [37]. Hoffland et al. [38] reported that the increase in the concentration of N in the tissue of tomato plants did not increase susceptibility to wilt caused by *Fusarium oxysporum* f. splycopersici but to bacterial spot (*Pseudomonas syringae pv* tomato) and tomato mildew (*Oidium lycopersicum*).

In potato crop cv. Alpha susceptible to late blight was fertilized with nitrogen rates of 0-320 kg/ha for two years, ammonium nitrate was used as N source. The results of this study show that a maximum leaf infection 20% in 1998 and 90% in 1999 was obtained. Deficiencies and excesses of N may favour the occurrence of late blight, so the recommended amount for the Toluca valley (180 kg/ha) meets the needs of the crop and reduces the degree of infection of late blight. In the case of high doses of nitrogen, the infection was initiated during maximum vegetative growth stage [39].

Smith [40] showed that the $Ca(NO_3)_2$ can be used as N source in strawberry cv. to decrease the incidence of *Colletotrichum fragariae*. Otherwise occurs when ammonia was used as N source.

Moreover, in plants veil (*Gypsophila paniculata*), highly susceptible to the disease of deformation, it reduced the incidence of the disease to almost zero at a concentration of 360 mg/L of NH_4^+. Opposite effect occur when plants are fertilized with NO_3^- [41].

In gladiolus, low and high concentrations of N, regardless of source, had no effect on corm rot caused by *Fusarium oxysporum* f. sp. *Gladiolus* [42].

4. Conclusions

There is little recent research performed as to the effect of nitrogen supply, mainly in the form of NH_4^+ on plants; therefore, it is of outmost importance to conduct further studies to define the response of ornamental and horticultural plants to NH_4^+ nutrition since there is a huge variability among species and cultivars on the maximum levels they can tolerate.

However, N is the element with significant effect on the yield and quality of horticultural products. Their availability and delivery form (NO_3^- or NH_4^+, alone or in combination) modify the response of crops depending on the species, variety, climate and soil conditions.

Most crops are susceptible to excessive levels of NH_4^+, however, when the supply is adequate and in accordance with the species growth, it promotes development and increases yields of plants. The concentration of NH_4^+ with respect to NO_3^- should not exceed 20% of total N.

References

[1] R.N. Roy, A. Finck, G.J. Blair, H.S.L. Tandon, Plant nutrients and basics of plant nutrition: FAO, Fertilizer and Plant Nutrition Bulletin 16 (2006) 25-42.

[2] C. Gallegos-Vázquez, E. Olivares-Sáenz, R. Vázquez-Alvarado, F. Zavala-García, Nitrate and ammonium uptake by cactus pear in hydroponics, Terra Latinoamericana 18 (2000) 133-139. (in Spanish)

[3] P. Marschner, Mineral Nutrition of Higher Plants, 3rd ed., Academic Press Publishers, London, 2012, p. 651.

[4] N. Bernstein, M. Ioffe, Effects of supplied nitrogen form and quantity on growth and postharvest quality of *Ranunculus asiaticus* flowers, Hort. Science 40 (2005) 1879-1886.

[5] V.A. Barker, H.A. Mills, Ammonium and nitrate nutrition of horticultural crops, Hort. Rev. 2 (1980) 395-423.

[6] M.R. Bugarín, G.A.C. Baca, J.H. Martínez, J.L.T. Tirado, Ammonium/nitrate ratio and total ion concentration in the nutrient solution on chrysanthemum growth—II. Nutrient uptake in leaves, Terra Latinoamericana 16 (1998) 125-134. (in Spanish)

[7] Y. Jingquan, C. Dewei, Effects of different nitrogen forms on tomato grown in carbonized rice hull, Soilless Culture 4 (1988) 51-61.

[8] T. Kraiser, D.E. Gras, A.G. Gutierrez, B. Gonzalez, R.A. Gutierrez, A holistic view of nitrogen acquisition in plants, Journal Exp. Bot. 62 (2011) 1455-1466.

[9] C. Ehaliotis, I. Massas, G. Pavlou, Efficient urea and KNO_3^- uptake by vegetable plants using fertigation, Agronomy for Sustainable Development 30 (2010) 763-768.

[10] H.M. Coraspe-León, T. Muraoka, V.I. Franzini, F.S.E. Contreras, P.C.T. Ocheuze, NH_4^+ and NO_3^- uptake by potato in the tuber seed production, Agronomía Tropical 59 (2009) 45-58. (in Spanish)

[11] V.A. Sisson, T.W. Rufty, R.E. Williamson, Nitrogen-use efficiency among flue-cured tobacco genotypes, Crop Sci. 31 (1991) 1615-1620.

[12] S. Parra-Terraza, E. Salas-Núñez, M. Villarreal-Romero, S. Hernández-Verdugo, P. Sánchez-Peña, Nitrate/ammonium/urea proportions and potassium concentrations in the production of tomato seedlings, Revista Chapingo Serie Horticultura 16 (2010) 37-47.

[13] K. Mengel, E.A. Kirkby, Principles of Plant Nutrition, 5th ed., Kluwer Academic Publishers, Dordrecht, 2001, p. 849.

[14] H. Ikeda, T. Xuewen, Urea as an organic nitrogen source for hydroponically grown tomatoes in comparison with inorganic nitrogen sources, Soil Sci. Plant Nutr. 44 (1998) 609-615.

[15] S.J. Tabatabaei, L.S. Fatemib, E. Fallahi, Effect of ammonium: Nitrate ratio on yield, calcium concentration and photosynthesis rate in strawberry, J. Plant Nutr. 29 (2006) 1273-1285.

[16] Y. Zhou, Y. Zhang, X. Wang, J. Cui, X. Xia, K. Shi, et al., Effects of nitrogen form on growth, CO_2 assimilation, chlorophyll fluorescence and photosynthetic electron allocation in cucumber and rice plants, J. Zhejiang Univ. Sci. B. 12 (2011) 126-134.

[17] G.V. Rückert, A. Giani, Effect of nitrate and ammonium on the growth and protein concentration of *Microcystis viridis* Lemmermann (Cyanobacteria), Rev. Bras. Bot. 27 (2004) 50-55.

[18] D.T. Britto, H.J. Kronzucker, NH_4^+ toxicity in higher plants: A critical review, Plant Physiol. 159 (2002) 567-584.

[19] E. Simonne, A. Simonne, L. Wells, Nitrogen source affects crunchiness, but not lettuce yield, Journal Plant Nutr. 24 (2001) 743-751.

[20] B. Lasa, S. Frechilla, C. Lamsfus, P.M. Aparicio-Tejo, The sensitivity to ammonium nutrition is related to nitrogen accumulation, Sci. Hort. 91 (2001) 143-152.

[21] R.H. Roosta, A. Sajjadinia, A. Rahimi, K.J. Schjoerring, Responses of cucumber plant to NH_4^+ and NO_3^- nutrition: The relative addition rate technique vs. cultivation at constant nitrogen concentration, Sci. Hort. 121 (2009) 397-403.

[22] P. Preciado-Rangel, A. Lara-Herrera, M.A. Segura-Castruita, E.O. Rueda-Puente, J.A. Orozco-Vidal, P. Yescas-Coronado, et al., Effect of ammonium and phosphate on the growth of cv. jalapeño pepper seedlings, Terra Latinoamericana 26 (2008) 37-42. (in Spanish)

[23] M. Lorenzo, C. Cid, J.M. Siverio, M.C. Ruano, Effects of sodium on mineral nutrition in rose plants, Ann. Appl. Biol. 137 (2000) 65-72.

[24] T.W. Coolong, W.M. Randle, The effects of calcium chloride and ammonium sulfate on onion bulb quality at harvest and during storage, Hort. Science 43 (2008) 465-471.

[25] A.L. Fleming, D.T. Krizek, R.M. Mirecki, Influence of ammonium nutrition on the growth and mineral composition of two chrysanthemum cultivars differing in drought tolerance, Journal Plant Nutr. 10 (1987) 1869-1881.

[26] W. Claussen, F. Lenz, Effect of ammonium and nitrate on net photosynthesis, flower formation, growth and yield of eggplants (*Solanum melongena* L.), Plant and Soil 171 (1995) 267-274.

[27] L. Dufour, V. Guérin, Nutrient solution effects on the development and yield of *Anthurium andreanum* Lind. in tropical soilless conditions, Sci. Hort. 105 (2005) 269-282.

[28] J.Y. Ruan, J. Gerendas, R. Hardter, B. Sattelmacher, Effect of nitrogen form and root-zone pH on growth and nitrogen uptake of tea (*Camellia sinensis*) plants, Annals of Botany 99 (2007) 301-310.

[29] R.L. Darnell, G.W. Stutte, Nitrate concentration effects on NO_3^- uptake and reduction, growth and fruit yield in strawberry, Journal Am. Soc. Hortic Sci. 126 (2001) 560-563.

[30] L.A. Ojeda-Real, P. Lobit, R. Cárdenas-Navarro, O. Grageda-Cabrera, R. Farías-Rodríguez, E. Valencia-Cantero, et al., Effect of nitrogen fertilization on quality markers of strawberry (*Fragaria* × *ananassa* Duch. cv. Aromas), Journal Sci. Food and Agricul. 89 (2009) 935-939.

[31] E.A. Kirkby, A.H. Knight, Influence of the level of nitrate nutrition on ion uptake and assimilation, organic acid accumulation and cation-anion balance in whole tomato plants, Plant Physiol. 60 (1977) 349-353.

[32] J.M. Choi, A. Latigui, C.W. Lee, Growth and nutrient uptake responses of “Seolhyang” strawberry to various ratios of ammonium to nitrate nitrogen in nutrient solution culture using inert media, African J. Biotech. 10 (2011) 12567-12574.

[33] T.S. Taghavi, M. Babalar, A. Ebadi, H. Ebrahimzadeh, A.M. Ali, Effects of nitrate to ammonium ratio on yield and nitrogen metabolism of strawberry (*Fragaria* × *ananassa* cv. Selva), Inter. J. Agri. Biol. 6 (2004) 994-997.

[34] B.R. Jeong, E.J. Lee, Growth of plug seedlings of *Capsicum annuum* as affected by ion concentration and NH_4^+:NO_3^- ratio of nutrient solution, Acta Hort. 481 (1999) 425-431.

[35] V. Tavernier, S. Cadiou, K. Pageau, R. Laugé, M. Reisdorf-Cren, T. Langin, et al., The plant nitrogen mobilization promoted by *Colletotrichum lindemuthianum* in phaseolus leaves depends on fungus pathogenicity, Journal Exp. Bot. 58 (2007) 3351-3360.

[36] M.G. Sayilikan, S. Bozkurt, M. Kara, S. Telli, The effects of nitrogen forms and rates under different irrigation levels on yield and plant growth of lettuce, Journal Cell Plant Sci. 1 (2010) 33-40.

[37] Y. Spiegel, E. Cohn, U. Kafkafi, The influence of ammonium and nitrate nutrition of tomato plants on parasitism by the root-knot nematode, Phytoparasitica 10 (1982) 33-40.

[38] E. Hoffland, M.J. Jeger, M.L. van Beusichem, Effect of nitrogen supply rate on disease resistance in tomato depends on the pathogen, Plant and Soil 218 (2000) 239-247.

[39] O.A. Rubio-Covarrubias, N.J. Grünwald, M.A. Cadena-Hinojosa, Influence of nitrogen on late blight infection in potato cultivation in Toluca, Mexico, Terra Latinoamericana 23 (2005) 487-493. (in Spanish)

[40] B.J. Smith, Influence of nitrogen, phosphorus and potassium on the severity of strawberry anthracnose crown rot, Acta Hort. 842 (2009) 235-238.

[41] Y. Ben-Yephet, M. Reuven, A. Zviebil, Y. Szmulewich, I. Lavkovits, T. Markovits, et al., Effect of nutrition on deformation disease in *Gypsophila paniculata* mother plants, Phytopathol. 96 (2006) 771-776.

[42] S.S. Woltz, R.O. Magie, Gladiolus fusarium disease reduction by soil fertility adjustments, Proc. Fla. State Hortic. Soc. 88 (1975) 559-562.