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 (NO₃⁻) or ammonium (NH₄⁺) has different effects on plant development. The NO₃⁻ 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 NH₄⁺ is the easiest way of assimilation but is highly toxic when the only source or with respect to the concentration of NO₃⁻ is too high. To avoid toxicity, the NH₄⁺ 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 (NO₃⁻) and ammonium (NH₄⁺) [3], which affect the growth, morphology and the nutrient status [4]. Most of plant prefers NO₃⁻ because high concentration of NH₄⁺ is toxic for its metabolism [5]. However, the addition of an optimum rate of NH₄⁺ to a NO₃⁻-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].
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$_4$)$_2$SO$_4$] 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$_4^+$.  

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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% NH₄⁺, however, its roots had greater strength when nurtured with NO₃⁻ [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. sp. lycopersici 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(NO₃)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 NH₄⁺. Opposite effect occur when plants are fertilized with NO₃⁻ [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 NH₄⁺ on plants; therefore, it is of outmost importance to conduct further studies to define the response of ornamental and horticultural plants to NH₄⁺ 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 (NO₃⁻ or NH₄⁺, 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 NH₄⁺, however, when the supply is adequate and in accordance with the species growth, it promotes development and increases yields of plants. The concentration of NH₄⁺ with respect to NO₃⁻ should not exceed 20% of total N.

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