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Full Length Research Paper

Growth and nutrient uptake responses of 'Seolhyang' strawberry to various ratios of ammonium to nitrate nitrogen in nutrient solution culture using inert media

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The effect of the variation of NH_4^+:NO_3^-ratios (meq/l: 0:100, 40:60, 50:50, 65:35 and 100:0) in the nutrient solution on strawberry (*Fragaria × ananassa* var Seolhyang) growth was evaluated. A mixture of large particle size (2 to 5 mm) and small particle size (smaller than 1 mm) of perlite was used as growing substrate and the nutrient solutions were applied once a week to the root substrate. The growth responses were determined 120 days after transplanting. The use of NO_3^- as the sole source of nitrogen in the nutrient solution resulted in the highest vegetative growth among the treatments tested. On the contrary, the exclusive use of NH_4^+ in the nutrient solution suppressed plant growth severely. The initial symptoms of ammonium toxicity appeared on the lower leaves, with the curling down of the old leaves. The margins turned brown and finally died. The introduction of the two nitrogen forms as the treatment ratio 60:40 (NH_4^+:NO_3^-) resulted in the optimal growth performance and nutrient uptake of this variety. The rate K/Ca+Mg=0.57, which was close to the best rate 0.67, allowed the optimal uptake of all nutrients. The data of the growth characteristics, nutrient content and electrical conductivity (EC) and pH were subjected to a polynomial regression analysis. The results show a high correlation between these data and the variation of NH_4^+:NO_3^- ratios. The values of the fresh and dry weight and N content of above-ground plant tissue to this variation were linear, with R^2 coefficients of 0.95*, 0.94**, and 0.71*. The changes in the NO_3^- concentration in the petiole sap, EC and pH of the root substrate were quadratic, with a coefficients of R^2= 0.99***, 0.98***, and 0.73*.**

Key words: Growth characteristics, NH_4^+: NO_3^- ratios, nutrient content, strawberry.

INTRODUCTION

Since the breeding of the 'Seolhyang' strawberry (*Fragaria × ananassa* Duch.) by crossing the Akihime (M) and the Read Pearl (F) (Kim et al., 2004) varieties in Korea, the cultivation area of this variety has grown rapidly. The area covered by the new variety is estimated to be more than 60% of the total strawberry cultivation area (6,800 ha) in Korea (unpublished data). The strong points of this variety are vigorous growth habits and very high productivity.

The 'Seolhyang' strawberry has unique nutrient uptake characteristics compared to the other varieties. Regarding soil cultivation in a green house, the pH in the root rhizosphere drops to 4.6 for this variety, whereas in other varieties it is maintained at around 6, when analyzed 5 weeks after transplanting (unpublished data). This situation can be improved by adjusting the NH_4^+:NO_3^- ratios of the total N supplied through nutrient solution; this ratio can serve as the main tool to balance the total cation-to-anion uptake ratio and maintain the pH within the desired range (Babiker et al., 2004; Paz and Ramos, 2004).

The form of the N source has been shown to influence

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the growth, yield, fruit quality, and chemical composition of the plant tissue in strawberries and other plants (Kotsiras et al., 2002; Tabatabaei et al., 2006), as crops are very sensitive to various ratios of NH_4^+: NO_3^- in the nutrient solution (Sonneveld, 2002). According to Guo et al. (2002) and Bruck and Guo (2006), different NH_4^+:NO_3^- ratios can affect the rate of plant growth as well as the biomass allocation. Inappropriate levels result in phytotoxicity and impair the product quality and quantity (Tabatabei et al., 2007; Ingestad, 2006). When NH_4^+ is the sole N source, plants can develop symptoms of toxicity and root growth can be severely impaired (Lasa et al., 2001). Moreover, according to Britto and Kronzucker, (2002), the NH_4^+ as the unique source of N usually has deleterious effects on plant growth and can result in toxicity symptoms in many plants. In contrast, plant root growth is only slightly affected when NO_3^- is the sole N source (Ruan et al., 2007). Because the NH_4^+:NO_3^- ratios during fertilization affect the rhizosphere pH and nutrient uptake as mentioned above, the best ratios of the two nitrogen sources should be determined for the cultivation of the 'Seolhyang' strawberry. This ratio can differ depending on the physiological stage in a single variety (Marschner, 1995). However, strawberries have several overlapping stages in a single floral stalk for a periodical distribution of physiological stages (Choi and Latigui, 2008; Risser and Navatel 1997). This makes the determination of the best ratios to meet all physiological stages difficult.

For this purpose, and to improve strawberry fertilization, we compared solutions containing two sources of nitrogen, NH_4^+ and NO_3^-, under the proportions of 40:60, 50:50, 65:35, 100:0 and 0:100, respectively. Britto and Kronzucker (2002) showed that the contribution of both ammonium and nitrate to culture medium improves the strength and reduces leaf chlorosis. Marschner (1995) showed that 80% NO_3^- and 20% NH_4^+ ensures in most cases, the best possible balance.

The objective of this study was to determine the effect of several ratios of NH_4^+:NO_3^- in the nutrient solutions on the growth and development of the 'Seolhyang' strawberry in growth stage prior to flowering. Then, according to the results, we improve these solutions for better absorption of all nutrients through the introduction of a new ionic equilibrium value.

MATERIALS AND METHODS

Treatment solutions

Hoagland solution (Hoagland and Arnon, 1950) was modified in order to make three treatment solutions containing different NH_4^+ to NO_3^- ratios: 40:60, 50:50 and 65:35 (Table 1). The ionic balances of macro cations (K^+, Ca^{2+} and Mg^{2+}) were similar according to the ratio K^+/ (Ca^{2+} + Mg^{2+}) = 0.57. Treatments with 0:100 and 100:0 as the ratios for NH_4^+:NO_3^- were used to determine the impact of the two exclusive nitrogen forms on toxicity development and plant growth. $H_2PO_4^-$ was used instead of HPO_4^{2-} in the 0:100 treatments (Table 1) to adjust ionic balance of macro cations because KH_2PO_4 contains less K compared to K_2HPO_4. This treatment solution was composed of 6 meq/l of K (Table 1), which is the highest concentration among all treatments tested.

The increase of SO_4^{2-} (Table 1) from 2 to 7 meq/l was due to the use of $(NH_4)_2SO_4$ to increase the concentration of NH_4^+ required for the 100:0 treatment. The variation from 6 to 8 meq/l in Cl^- concentration for the 40:60, 50:50 and 63:35 treatments was due to the use of KCl instead of KNO_3 and KSO_4. The variations in the ratio of K/N from 0.21 to 0.60 and the sum of ion value from 13 to 21 meq/l were necessary due to the quantitative variations of the total nitrogen in the treatment solutions.

The five treatment solutions contained equal amount of six micronutrients (mg/l): $MnCl_2 \cdot 4H_2O$, 1.81; H_3BO_3, 2.86; $ZnSO_4 \cdot 7H_2O$, 0.22; $CuSO_4 \cdot 5H_2O$, 0.08; $H_2MoO_4 \cdot H_2O$, 0.09; and $Na_2FeEDTA$, 0.79. The pH levels of all solutions were adjusted to 6.0. There were four replicates for each treatment with 2 plants per replicate.

Plants and experimental design

The experiments were carried out in the controlled environment of a glasshouse, located in Daejeon (36° 20' N, 127° 26' E), Korea. The mean day and night temperatures inside the glasshouse were 24 and 15°C, respectively, during the experimental period. The relative humidity was 60 to 70% and the average photoperiod was 15 h with a photosynthetic photon flux density of 330 to 370 $\mu mol/m^2/s^1$.

Plug-grown 'Seolhyang' strawberry seedlings at the three true-leaf stage were planted into plastic pots with an internal diameter of 15 cm and a volume of 1600 ml of a 1:1 mixture of coarse (2 to 5 mm) and fine (smaller than 1 mm in diameter) perlite.

The plants were irrigated with distilled water for the first 45 days after planting to decrease the tissue nutrient levels and the older leaves were removed, leaving only 3 newly formed leaves per plant as the baseline measure. The plants were then fertilized with the NH_4^+/NO_3^- treatment solutions once a week. Between the weekly applications of the fertilizer solution, the plants were irrigated with distilled water. During each fertilization or irrigation, the leaching percentage was controlled at 30 to 40% to avoid salt accumulation in the root media (Muñoz et al., 2008).

The crop growth as influenced by the treatment solutions was checked 120 days after planting, by measuring the number of leaves, leaf length and width, petiole length, crown diameter, and fresh and dry weights. The procedure to determine the crop growth followed the methods described by Choi et al. (2000).

Petioles of fully grown young leaves were also collected, 120 days after planting, and cut into 1 mm long segments for analysis. Samples were put into vial, with distilled water (1:10, w/w). Vials were occasionally shaken for 30 min by hand to allow the electrolytes to leak out from the petiole sections. After filtering with a Whatman No. 2 filter paper, the solutions were used for NO_3^--N analysis following the procedures of Cataldo et al. (1975).

Statistical analysis

Data from the growth measurements, tissue analyses, soil solution pH and electrical conductivity (EC) were subjected to a randomized complete block analysis of variance. The treatment means were separated via a LSD test. Data were also subjected to a polynomial regression analysis using the CoStat program (CoHort Software version 6.3, Monterey, CA).

Table 1. Composition of the nutrient solutions used to check for the effect of NH4:NO3 ratios on the growth and nutrient uptake of the 'Seolhyang' strawberry[z] .

NH_4:NO_3 ratio	NH_4^+ (meq/l)	NO_3^- (meq/l)	K^+ (meq/l)	Ca^{2+} (meq/l)	Mg^{2+} (meq/l)	SO_4^{2-} (meq/l)	HPO_4 (meq/l)	$H_2PO_4^-$ (meq/l)	Cl^- (meq/l)
0:100	0	10	6	5	2	2	0	1	0
40:60	4	6	4	5	2	2	1	0	6
50:50	7.5	7.5	4	5	2	2	1	0	8
65:35	7.5	4	4	5	2	5.5	1	0	8
100:0	11.5	0	2.5	5	2	7	1	0	13

[z]Micronutrients (mg/l solution): $MnCl_2 \cdot 4H_2O$, 1.81; H_3BO_3, 2.86; $ZnSO_4 \cdot 7H_2O$, 0.22; $CuSO_4 \cdot 5H_2O$, 0.08; $H_2MoO_4 \cdot H_2O$, 0.09; and Na_2 FeEDTA, 0.79.

RESULTS AND DISCUSSION

Effect on growth characteristics

Except for the leaf numbers, all growth characteristics of the 'Seolhyang' strawberry, 120 days after planting were significantly influenced by various NH_4^+:NO_3^- ratios in the nutrient solution (Table 2 and Figure 3). However, no significant differences in the number of leaves were noticed in all treatments. Nevertheless, the unique contributions of the 11.5 meq/l of NH_4^+ in 100:0 (NH_4^+: NO_3^-) treatment (Table 2) resulted in a decrease of the leaf length, leaf width, and petiole length. In contrast, the crown diameter was significantly larger in this treatment. Fresh and dry weights were also the lowest in 100:0 (NH_4^+: NO_3^-) treatment. These results are in agreement with those of Fallovo et al. (2009), who found that the exclusive use of NH_4 reduced the fresh and dry mass of the shoot by 70 and 50%, respectively. The edges (Figure 1) of the young leaves became dull green, wilted and curled backwards, and the older leaves were desiccated and scorched while the petioles remained green.

Claussen and Lenz (1999) and Rothstein and Cregg (2005) argued that the accumulation of NH_4^+ in the leaves can cause uncoupling of the electron transport due to photophosphorylation in the chloroplasts, resulting in a decreased of the photosynthetic rate. Chaillou et al. (1986) showed that a strict ammonium diet leads to the falling of rhizosphere pH due to the root excretion of H^+ ions. At low external pH, net excretion of protons is impaired and cytosolic pH may also fall, explaining the relationship between growth retardation and pH decline in ammonium fed plants (Marschner, 1995). These results show that NH_4^+ has unique contributions that are negative for crop growth.

In contrast, when NO_3^- was the sole source of N (0:100, NH_4^+: NO_3^-), the treatment (Table 2) resulted in an increase in the leaf width and petiole length and also resulted in the highest fresh and dry weights. The growth in terms of dry weight decreased lineally as the NH_4 ratios in nutrient solution were elevated (Figure 2). These results are supported by another study of Choi et al. (2008). However, Sasseville and Mills (1979) found that a lower weight of 8.6 g per plant was obtained with a ratio of 0:100. The NO_3^--N concentration in the petiole sap is also greater with the 0:100 treatments with lineally decreasing tendency as the ratios of NH_4^+:NO_3^- in the nutrient solution were elevated. But the no trend was observed in NH_4^+-N concentration.

In addition, it is evident, that the contribution of NO_3^- (0:100) resulted in the largest leaf development (Figure 1) compared to those in other treatments. As it can be verified in the same figure, a ratio of 40% NH_4^+ and 60% of NO_3^- resulted in balanced growth of the leaves as well as the largest leaf area (Table 2). This ratio promotes the development of fruit as well as runners because sole source of NO_3^- in fertilizer solution results in vegetative growth as indicated by Sharma et al. (2006). According to Marschner (1995), adjusting the NH_4^+:NO_3^- ratio of the total N supplied can serve as the main tool to balance the total cation-to-anion uptake ratio, appearing to be beneficial to the plant (Sonneveld, 2002).

When a ratio of 40% of NH_4 and 60% of NO_3^- was used, it resulted in an increased of the leaf length, leaf width, petiole length (Table 2), and leading to the highest fresh weight. Compared to other treatments, 40:60 (NH_4^+:NO_3^-) resulted in the best growth performance of this variety.

Effect on the nutrient content

Except for the Mn and total N contents (Table 3), the analysis of variance showed highly significant effects of various NH_4^+:NO_3^- ratios on the nutrient content based on the dry weight of the above-ground tissue. It was also verified that the ratios of 35:65 and 100:0 (NH_4^+:NO_3^-) resulted in the higher percentage of T-N than 0:100 treatment. These are different to the results of Tabatabei et al. (2006) who found that the highest tissue content of T-N was observed at 25:75 and 50:50 (NH_4^+: NO_3^-) in a strawberry solution.

Table 2. Influence of various NH_4 to NO_3 ratios in the nutrient solution on the growth characteristics of 'Seolhyang' strawberry, 120 days after transplanting.

NH_4:NO_3 ratio	Number of leaves (per plant)	Leaf length (cm)	Leaf width (cm)	Petiole length (cm)	Crown diameter (cm)	Fresh weight (g/plant)	Dry weight (g/plant)
0:100	28.5[az]	7.48[ab]	5.43[a]	12.50[a]	1.08[b]	16.7[a]	4.51[a]
40:60	26.0[a]	7.98[a]	5.38[a]	11.60[a]	0.98[b]	15.9[a]	3.62[b]
50:50	24.5[a]	7.53[ab]	5.38[a]	11.13[a]	0.97[b]	13.8[ab]	3.30[bc]
65:35	28.0[a]	6.70[bc]	4.90[ab]	9.08[b]	1.09[b]	11.1[bc]	2.55[cd]
100:0	23.5[a]	6.11[c]	4.20[b]	8.23[b]	1.28[a]	8.6[c]	2.12[d]
Linear	NS	*	*	**	*	***	***
Quadratic	NS	NS	*	**	***	***	***

[z]Mean separation by Duncan's multiple range test at $P \leq 0.05$. Values followed by the same letter within columns are not significantly different.
NS,*,**,***Non-significant or significant at $P \leq 0.05$, 0.01 and 0.001, respectively.

Table 3. Influence of various NH_4 to NO_3 ratios in the fertilizer solution on the nutrient content based on the dry weight of the above-ground tissue of 'Seolhyang' strawberry, 120 days after transplanting.

NH_4:NO_3 Ratio	T-N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Na (%)	Fe (mg/kg)	Mn (mg/kg)	Zn (mg/kg)	Cu (mg/kg)
0:100	1.32[bz]	0.66[b]	2.69[a]	1.87[a]	0.71[a]	0.07[b]	205.2[b]	105.2[a]	48.4[b]	12.1[b]
40:60	1.45[ab]	0.75[a]	2.13[b]	1.37[c]	0.65[ab]	0.07[b]	302.0[a]	93.8[ab]	60.7[b]	14.4[ab]
50:50	1.46[ab]	0.75[a]	2.35[b]	1.33[c]	0.63[ab]	0.07[b]	291. 7[a]	81.1[b]	46.1[b]	14.4[ab]
35:65	1.59[a]	0.75[a]	2.39[b]	1.39[c]	0.55[c]	0.08[b]	285.1[a]	96.5[a]	73.6[b]	16.3[a]
100:0	1.54[a]	0.73[a]	1.75[c]	1.59[b]	0.59[bc]	0.14[a]	301.9[a]	94.6[ab]	184.4[a]	13.9[ab]
Linear	**	NS	**	NS	**	**	*	NS	**	NS
Quadratic	**	*	*	***	**	***	*	NS	**	*

[z]Mean separation by Duncan's multiple range test at $P \leq 0.05$. Values followed by the same letter within columns are not significantly different.
[NS],*,**,***Non-significant or significant at $P \leq 0.05$, 0.01 and 0.001, respectively.

The response to the varied NH_4^+:NO_3^- ratios on the N content of above-ground tissue (Figure 2) was linear, as expressed as y=1.3546+0.0023x (R^2=0.7193***). The NO_3^- concentration in the petiole sap (Figure 4) had a determination coefficient of R^2= 0.99***. The judgment of nutritional status of crops through the NO_3-N concentrations in petiole sap is an easier way than those conventional method in which total nitrogen contents of above ground tissue is analysed. But there are no comparable data related to NO_3-N concentrations in petiole sap. In case of T-N in above ground tissue, Sharma et al. (2006) showed that a 3.5% of T-N (in dry weight basis) is necessary to obtain a normal fruit. According to their findings, additional nitrogen is needed in the solution for all the treatments of our research.

The lowest tissue phosphorus content was obtained when the rate was 0:100, this result being significantly lower than the ones for all the other treatments. The greatest contents were 0.75% for 40:60, 50:50 and 65:35 and 0.73% for 100:0, these results were not significantly different though (Table 3). Results obtained for P in this experiment are supported by the ones of Abbes et al. (1995) and Leikam et al. (1983), who worked with *Allium cepa*. The presence of NH_4^+ in the

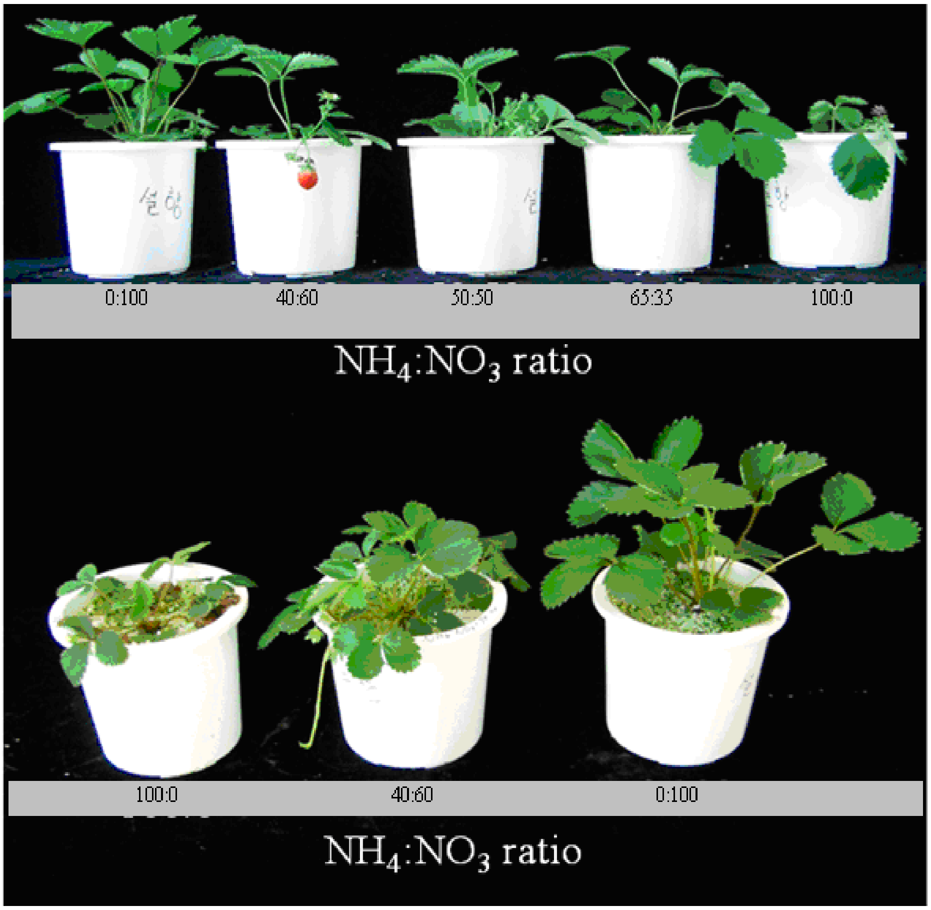

Figure 1. Differences in crop growth (upper) and ammonium toxicity (lower) of the 'Seolhyang' strawberry at 120 days after transplanting as influenced by various NH_4:NO_3 in the fertilizer solution.

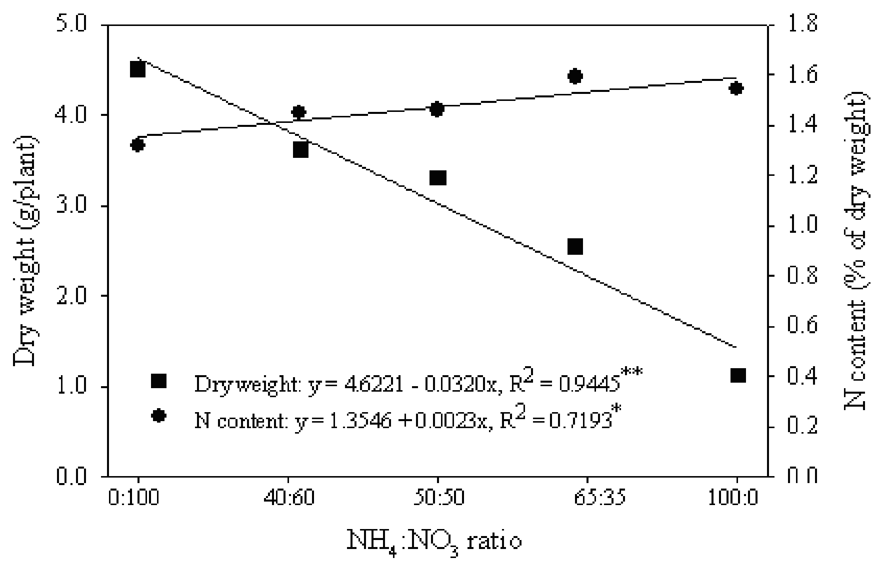

Figure 2. Influence of various NH_4 to NO_3 ratios in the fertilizer solutions on changes in the dry weight and N content of above-ground part of the 'Seolhyang' strawberry, 120 days after transplanting.

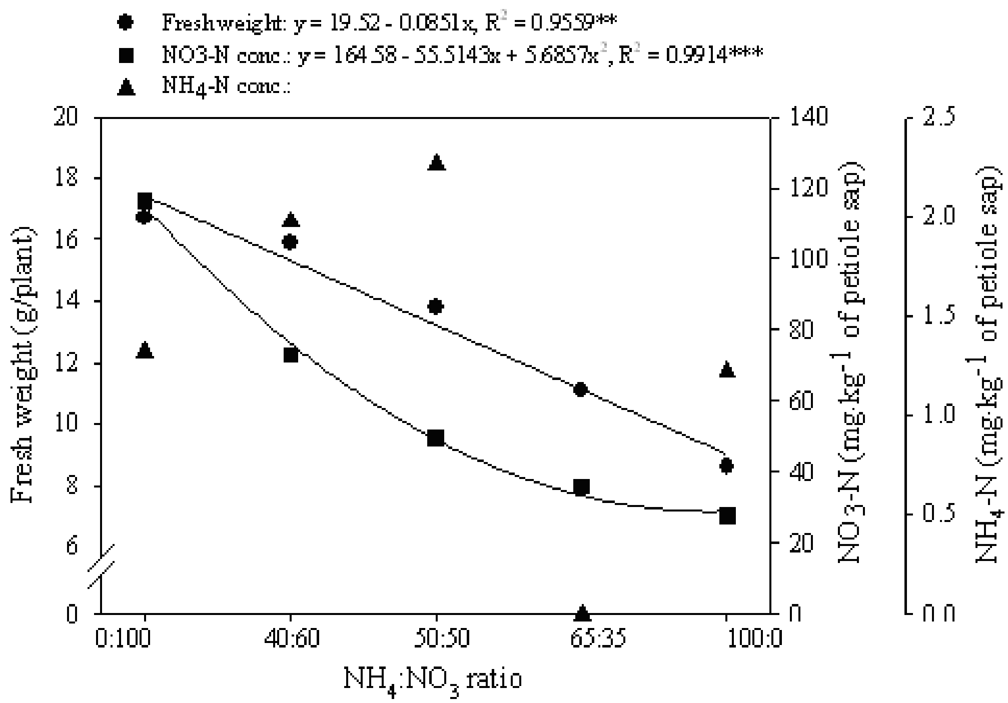

Figure 3. Influence of various NH_4 to NO_3 ratios in fertilizer solutions on fresh weight of above-ground plant tissue, NO_3-N and NH_4-N concentrations in the petiole sap of the 'Seolhyang' strawberry, 120 days after transplanting. The curve in the NH_4-N concentration was not significant as regards linear or quadratic fitting.

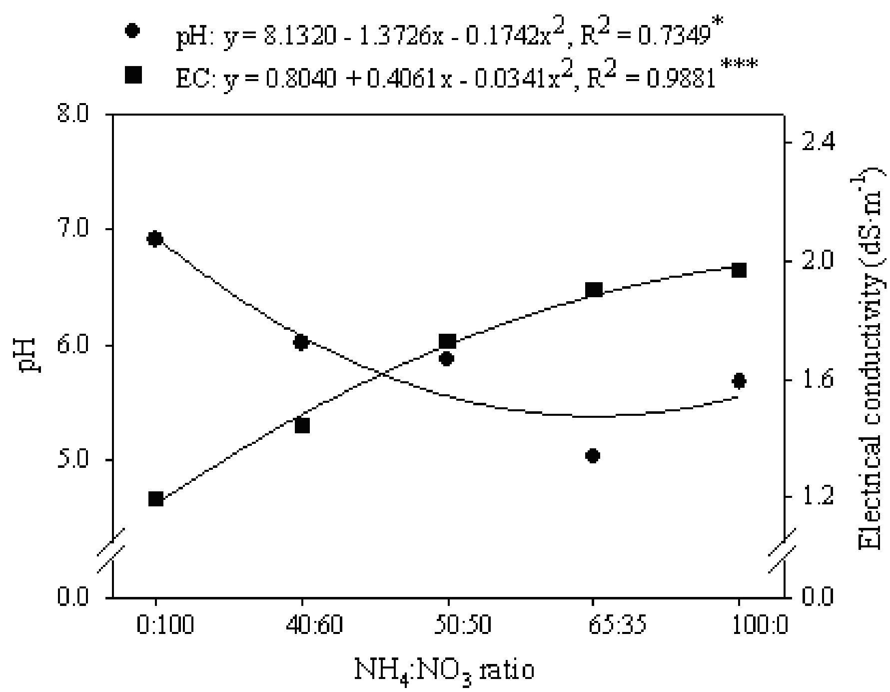

Figure 4. Effect of various NH_4 to NO_3 ratios in fertilizer solutions on changes in pH and EC of the soil solutions of root media, 120 days after transplanting of the 'Seolhyang' strawberry.

solution resulted in the highest phosphorus content, based on the dry weight of above-ground tissue.

However, the ratio of 0:100 resulted in the highest tissue K content (Table 3). Values for 40:60, 50.50 and 65.35 were, respectively 2.13, 2.35 and 2.37%, these results being significantly lower than the ones for the ratio 0:100. The ratio 100:0 showed the lowest content.

The ratio 0:100 resulted in the highest Ca^{2+} content (Table 3). This value was followed by the one obtained for ratio 100:0, the lowest contents being obtained with 40:60, 50.50 and 65:35, with rates of 1.37, 1.33 and 1.39%, respectively; nevertheless, all these values were significantly lower than the ones for 0:100. The highest rate of Mg^{2+}, 0.71%, was obtained with 0:100, followed by the ones for 40:60 and 50:50, respectively, with values of 0.65 and 0.63%, respectively. The lowest content of 0.55% was obtained with the ratio 65:35, but this value was statistically lower than all the others. In addition, the presence of NO_3^- alone or mixed with NH_4^+ gave the largest contents of K^+, Ca^{2+} and Mg^{2+}. Alan (1989) and Kotsiras et al. (2002) showed that the presence of a high concentration of NH_4^+ in a nutrient solution induced a decrease of these elements in the tissue contents, while NO_3^- had the opposite effect.

No sodium fertilizer was used in the experiment. However, the presence of Na was detected in all treatments. The highest rate of 0.14% was obtained with the ratio of 100:0. This was clearly due to the high storage capacity of this strawberry variety during the 120 day experimental period. Earlier, the plants had been in a nursery, with all of the elements they needed.

Regarding the micronutrients, it can be noted that the lowest and significantly different Fe content was obtained with 0:100, in contrast to the ratios 40:60, 50:50, 65:35 and 100:0, where no significant differences were noted. The highest contents of Zn and Cu were obtained with the ratios 100:0 and 65:35, respectively.

Effect on EC and pH

Electrical conductivity (EC) (Figure 4) increases from 1.2 dS/m with 0:100 to 2.0 dS/m with 100:0. This is why the elevation of NH_4 ratios in nutrient solution requires the increase in concentration of counter ion such as SO_4^{-2} in $(NH_4)_2SO_4$ (Table 1) and the solution EC for 100:0 was higher than those of 0:100 treatment (NH_4^+:NO_3^-) when crops were irrigated. However, this range has no negative effect on the growth of strawberries. According to Skiredj (2005), the standard parameter for EC is between 1.5 and 2.5 dS/m, which is in accordance with the results obtained in this study.

The pH decreased as NH_4^+ ratios in the fertilizer solution were elevated ranging between 5 and 6. This reduction is caused by the release of H^+ when plant roots absorb NH_4^+ (Marschner 1995). Nonetheless, the ratio of 0:100 resulted in a relatively high pH 7, due to the consumption of NO_3, despite the addition of 0.8 meq/l HNO_3 (d = 1.33, 38° B), which had reduced the initial pH of 6 to 5.5 (Figure 4), a condition necessary for the uptake of all micronutrients. According to Latigui (1992), this reduction may decrease the concentration of HCO_3^- presented in the nutrient solutions, as it increases the root rhizosphere pH during crop cultivation. According to Marschner (1995) adjusting the NO_3^-:NH_4^+ ratio from the total N maintains the pH within the desired range.

Conclusion

According to the plant growth results obtained in this study, we conclude that the NH_4^+: NO_3^- ratio of 40:60 is relatively less stringent (Latigui, 1992). However, this required some corrections. Initially, it was composed of (meq/l): 4 K^+, 5 Ca^{2+}, 2 Mg^{2+}, 4 NH_4^+, 6 NO_3^-, 10 (NH_4^++ NO_3^-), 2 SO_4^{2-}, 1 HPO_4^{2-}, and 6 Cl^- with the characterristics of pH 6, EC=1.460 dS·m^{-1}, K/ (Ca +Mg) = 0.57 and ∑cations = ∑anions = 15 meq/l. For this composition, we used the fertilizers KNO_3, K_2HPO_4, KCl, $Ca(NO_3)_2$, $MgSO_4$ and NH_4Cl. To improve this solution based on the results and literature findings, we have to reduce the concentration of NH_4^+ from 4 to 3.55 meq/l using the NH_4NO_3 fertilizer instead of NH_4Cl. This arrangement also allowed us to reduce the concentration of Cl^-, which unnecessarily increased the salinity of the substrate.

Other changes in the levels of K^+ and Ca^{2+} allowed $K^+/(Ca^{2+}+ Mg^{2+})$ to be equal to 0.72, which is ideal as regards the ionic balance at this stage of development for strawberries. The mono and biphosphate HPO_4^{2-} and $H_2PO_4^-$ have the same roles but vary in proportion according to the pH in a normal substrate. The use of $H_2PO_4^-$ would be more beneficial, as this ion predominates in acidic substrates such as that in the solution NH_4^+: NO_3^- at a ratio of 40:60 with a pH of approximately 5.5, which is necessary to avoid any precipitation of elements.

Depending on the results of this study, the new developed solution consisted of (meq/l): 5.15 K^+, 5.15 Ca^{2+}, 2 Mg^{2+}, 3.55 NH_4^+, 0.8 H^+, 10.65 NO_3^-, 14.20 (NH_4^++ NO_3^-), 2 SO_4^{2-}, 2 HPO_4^{2-}, 2 Cl^- with the characteristics pH 5.5, EC =1.620 dS/m, K/ (Ca +Mg) =0.72, ∑cations = ∑anions=16.65 meq/l. Therefore, after the results obtained, the solution was optimized as (in meq/l): 1.5 KNO_3, 2 K_2HPO_4, 2 KCl, 5.5 $Ca(NO_3)_2$, 2 $MgSO_4$, 3.55 NH_4NO_3 and 0.8 HNO_3 (d=1.33, 33°B) and (in µM/l): 20 B, 0.5 Cu, 20 Fe, 10 Mn, 0.5 Mo, 4 Zn.
The exclusive use of NH_4^+ or NO_3^- in the solution is not recommended as an optimal plant requirement.

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