

Ammonium (NH_4^+): Nitrate (NO_3^-) Ratio and its Relation to the Changes in Solution pH, Growth, Mineral Nutrition and Yield of Tomatoes Grown in Nutrient Film Technique

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Keywords: NH_4^+ : NO_3^- ratio: growth, pH, water uptake, yield, blossom-end rot, mineral nutrition

ABSTRAK

Pengaruh nisbah $\text{NH}_4^+:\text{NO}_3^-$ terhadap pertumbuhan, pengambilan air, pH larutan, pemakanan tanaman dan hasil tanaman tomato telah dikaji menggunakan teknik nutrien cetek. Enam perlakuan rawatan nisbah $\text{NH}_4^+:\text{NO}_3^-$ telah diberikan kepada tanaman: 0:100 dengan dan tanpa kawalan pH; 12.5:87.5, 25:75, 37.5:62.5 dan 50:50 tanpa kawalan pH. Kajian mendapati pH didalam larutan meningkat apabila berada di dalam $\text{NH}_4^+:\text{NO}_3^-$ dengan nisbah 0:100 dan 12.5:87.5, tetapi menurun pada nisbah 50:50. Nisbah $\text{NH}_4^+:\text{NO}_3^-$ yang tinggi mengurangkan pertumbuhan daun dan akar tanaman. Pengurangan ini mungkin disebabkan oleh pengurangan pengambilan air. Berat basah buah juga dikurangkan dan peratus kejadian reput hujung buah meningkat apabila tanaman didedahkan pada nisbah $\text{NH}_4^+:\text{NO}_3^-$ yang tinggi. Nisbah $\text{NH}_4^+:\text{NO}_3^-$ yang tinggi meningkatkan kandungan N dan mengurangkan kandungan Ca dalam bahagian tisu tanaman. Kandungan P, K dan Mg menurun didalam tisu daun dengan peningkatan nisbah $\text{NH}_4^+:\text{NO}_3^-$.

ABSTRACT

The effects of $\text{NH}_4^+:\text{NO}_3^-$ ratio on growth, water uptake, solution pH, mineral nutrition and yield of tomatoes were investigated using the nutrient film technique. There were six $\text{NH}_4^+:\text{NO}_3^-$ ratios: 0:100 with and without pH control; 12.5:87.5, 25:75, 37.5:62.5 and 50:50 without pH control. There was an increase in pH of the nutrient solution with 0:100 and 12.5:87.5 ratios, but the pH decreased with 50:50 ratio. Higher $\text{NH}_4^+:\text{NO}_3^-$ ratio reduced leaf and root growth. The reduction in leaf and root growth could be attributed to reduction of plant water uptake. Fruit fresh weight was reduced and the percentage of blossom-end rot increased with higher ratio of $\text{NH}_4^+:\text{NO}_3^-$ in the solution. Increased ratio of $\text{NH}_4^+:\text{NO}_3^-$ increased N content and decreased Ca content in all the plant tissues. P, K and Mg content decreased in leaf tissue with increasing $\text{NH}_4^+:\text{NO}_3^-$ ratio.

INTRODUCTION

Cultivation of tomatoes by conventional methods on soil in lowland areas of Malaysia is limited due to the unfavourable weather and occurrence of soil-borne pathogens. To overcome these limitations, the technology of soilless crop production has been developed and has proved advantageous (Lim 1985). Nutrient film technique (NFT) is one of the soilless culture systems used for cultivation of horticultural crops.

One factor that may contribute to the effectiveness of mineral nutrition in NFT system is the form of nitrogen added to the nutrient formulation. In common with conventional methods, nitrogen is supplied to the plants in the form of ammonium ion (NH_4^+) and/or nitrate ion (NO_3^-). Cooper (1979), Iwata (1983) and Ikeda and Yamada (1984) reported that growth and plant development are enhanced by the use of NO_3^- in the fertilizer formulation. However, there are also reports indicating better

growth if both NH_4^+ and NO_3^- are used as the N source (Cox and Reisenauer 1973; Follett and Doaglas 1987). Costellane *et al.* (1987) reported maximum growth of tomatoes when 25% NH_4^+ was used in the liquid feed. Similarly, Monnerat *et al.* (1982) reported that $\text{NH}_4^+:\text{NO}_3^-$ ratio of 60:40 resulted in increased dry weight accumulation. NH_4^+ salts are cheaper sources of nitrogen than NO_3^- salts. Furthermore, uptake of NH_4^+ is usually coupled with H^+ enrichment in the nutrient solution which consequently minimises the rise in solution pH.

This study was undertaken to investigate growth, water uptake, changes in solution pH, mineral nutrition and yield of tomatoes grown in NFT-trough system.

MATERIALS AND METHODS

The experiment was conducted at the Hydroponic Unit, Universiti Pertanian Malaysia. The plants were grown under glasshouse conditions with air temperatures ranging from 27-35°C and relative humidity of 65-80%.

Four-week-old uniform-sized tomato (*Lycopersicon esculentum* Mill) plants var. Sweet Chelsea were transplanted into the NFT-trough system. The plants were grown in the recirculating water for one week and then subjected to treatments of six $\text{NH}_4^+:\text{NO}_3^-$ treatments (Table 1)

The $\text{NH}_4^+:\text{NO}_3^-$ ratio was calculated based on the concentration of salts used in the nutrient formulation. Cooper formulation full strength solution (Cooper 1979) was modified so that the desired $\text{NH}_4^+:\text{NO}_3^-$ ratio was achieved while the N level was maintained. Chloride and sulphate salts were used to replace specific cations and anions and to maintain a constant solution conductivity. The treatments were arranged in a randomized design with four replicates. Seven plants spaced 40 cm apart in a trough

represented a replicate. Each trough had its own catchment tank supplying nutrient solution to the plants (Jarret and Charter 1981). Troughs were spaced 55 cm apart.

As the relative concentration of salts was not continuously monitored, the nutrient solution in the catchment tank was replenished fortnightly. When new nutrient solution was prepared, pH was adjusted to 6.0 using sulphuric acid, after which it was not readjusted. Changes in pH were monitored daily.

After 14 weeks, plants were sampled for leaf, root and stem dry weight by oven drying at 80°C for 48 hours. Leaf area was determined using an automatic leaf area meter (Delta-T Devices). Leaf area index (LAI) was recorded in week 7 using a 'Plant Canopy Analyser' (LiCor 2000).

Plant water uptake was recorded over 24 hours by measuring water loss from the catchment tank. Accumulation of radiant energy was also recorded concurrently with water loss from the catchment tank using solarimeters attached to a microvolt integrator (MV2, Delta-T Devices).

Flower number was recorded to determine fruit set in the various treatments. Fruits were harvested at the orange to red stage and the number of fruits and their fresh weight were recorded. Fruit physical characters were also recorded. Fruit diameter was recorded using a vernier caliper. Total soluble solids were determined from 2-3 drops of expressed fruit juice using a hand refractometer. Fruit dry weight was determined after 72 hours oven drying at 80°C.

Nutrient analysis was performed on dry samples of plant parts according to the standard procedure described by Mohd. Haniff *et al.* (1990). Plant parts were sampled in week 5 and 12 for mineral nutrition determination. Total N, P and K were determined using an autoanalyser

TABLE 1
 $\text{NH}_4^+:\text{NO}_3^-$ ratios of fertiliser used in nutrient film technique experiments on tomato

Treatment	NH_4^+	NO_3^-	pH
T1	0	100.0	maintained at 6.0
T2	12.5	87.5	not controlled
T3	25.0	75.0	not controlled
T4	37.5	62.5	not controlled
T5	50.0	50.0	not controlled
T6	0	100.0	not controlled

(Technicon Auto Analyser). Ca and Mg were determined using an atomic absorption spectrophotometer.

RESULTS AND DISCUSSION

pH of Nutrient Solution

The pH fluctuated within a narrow range in weeks 3 and 4 (Fig. 1a). At this stage, plants were probably capable of absorbing the nutrients actively, which would result in less imbalance of nutrients in the catchment tank. By weeks 5 and 6, pH of 100% NO_3^- in T6, showed a marked increase (Fig. 1b). On the other hand, nutrient solution containing NH_4^+ ratio of more than 37.5% resulted in a decline in the pH level, but did not fall below pH 5.5. In weeks 7 and 8, the pH for T6 exceeded 7.3 (Fig. 1c). In contrast, when the proportion of NH_4^+ was 50% (T5) the pH in the nutrient solution did fall below 5.5. The changes in pH determined in weeks 10 and 11 followed a similar trend as weeks 5 and 6 (Fig. 1d). The higher pH values obtained with higher proportions of NO_3^- agree with those observed by Ikeda and Osawa (1981). In contrast, higher proportions of NH_4^+ (T4, T5) resulted in decreased pH in the nutrient solution, which is attributable to acidification of the nutrient solution due to the release of H^+ in the active transport of nutrients, a phenomenon reported by other investigators (Maynard and Barker 1969; Qasem and Hill 1993).

Plant Vegetative Growth

Table 1 illustrates leaf, stem and root growth as influenced by different $\text{NH}_4^+:\text{NO}_3^-$ ratios. Leaf area and dry weight were significantly reduced with NH_4^+ higher than 37.5% in the nutrient solution. For leaf area, increasing the proportion of NH_4^+ to 37.5 and 50% caused a 17% and 20% reduction in leaf area compared with the 100% NO_3^- treatment.

Treatments with higher proportions of NH_4^+ reduced plant dry weight, the reduction being greatest in the roots, followed by stems and leaves. The NH_4^+ ions hasten breakdown of carbohydrates (Barker *et al.* 1965), uncouple photosynthetic phosphorylation (Gibbs and Colo 1959) and play a significant role in the disruption of chloroplast membrane (Purich and Barker 1967).

The present study did not attempt to confirm the above-mentioned role of NH_4^+ , but it provided evidence that there may be a possible effect on plant-water relations which caused reductions in leaf area and dry weight. Fig. 2 illustrates the influence $\text{NH}_4^+:\text{NO}_3^-$ ratio on plant water uptake. Water uptake was reduced with higher proportions of NH_4^+ ; the effect was particularly obvious with increasing irradiance. The role of water relations in influencing growth when plants are subjected to increasing NH_4^+ in the nutrient solution agrees with reports by Pill and Lambeth (1977) and Pill *et al.* (1978). Quebedeaux and Ozbun (1973) suggested NH_4^+ N alters the physiological mechanisms involved in uptake and movement of water. The inhibitory effect of NH_4^+ on water uptake may involve two mechanisms: NH_4^+ may directly interfere with water uptake, and NH_4^+ may cause an anatomical and physiological change requiring a longer period for recovery.

Yield

The effect of $\text{NH}_4^+:\text{NO}_3^-$ ratios on fruit fresh weight is consistent with fruit yield being reduced as NH_4^+ ratio increases. Increasing the proportion of NH_4^+ to 25, 37.5 and 50% resulted in reductions in fruit fresh weight compared with 100% NO_3^- (Table 2). This reduction in fruit fresh weight may result from reduced assimilate being translocated due to reduced leaf area when the proportion of NH_4^+ is higher. Increasing the proportion of NH_4^+ to more than 25% significantly increased the percentage of fruits with blossom-end rot (BER) (Table 3). It is well known that this disorder in tomatoes is associated with reduced Ca^{++} translocation to the growing region of the fruit (Cerda *et al.* 1979; Ehret and Ho 1986). Moreover, the partitioning of Ca^{++} concentration in different regions of leaves and fruit shows a clear involvement of NH_4^+ in suppressing the translocation of Ca^{++} to growing region (Fig. 3). Ca^{++} concentration in the root did not differ indicating that Ca^{++} uptake at the root surface was not inhibited by the presence of NH_4^+ at early stages of plant growth, but deficiency in Ca^{++} may arise from translocation to the actively growing regions. The $\text{NH}_4^+:\text{NO}_3^-$ ratio did not produce an appreciable effect on fruit size, total soluble solids and percentage of fruit dry matter.

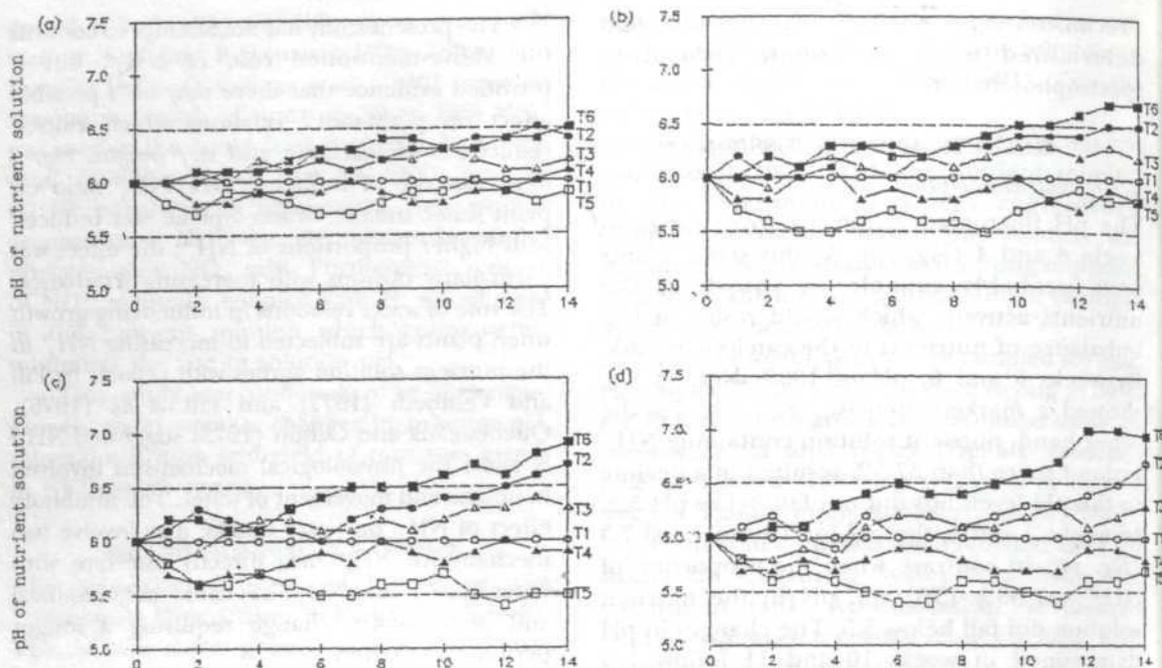


Fig. 1: Changes of pH in the nutrient solution influenced by $NH_4^+ : NO_3^-$ ratio at various durations
 a) weeks 3-4 b) weeks 5-6 c) weeks 7-8 d) weeks 9-10

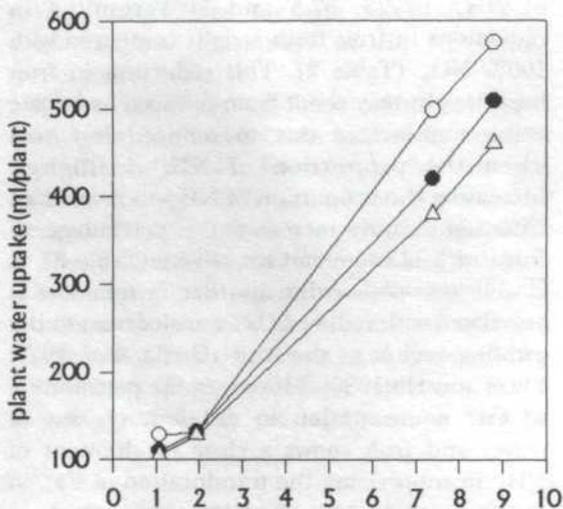


Fig. 2: Plant water uptake (ml/plant) as influenced by accumulated radiant energy at different $NH_4^+ : NO_3^-$ ratios. O=0:100; •=25:75 and Δ= 50:50. Measurement of radiant energy was done concurrently with the plant water uptake throughout the day therefore radiant energy is not replicated

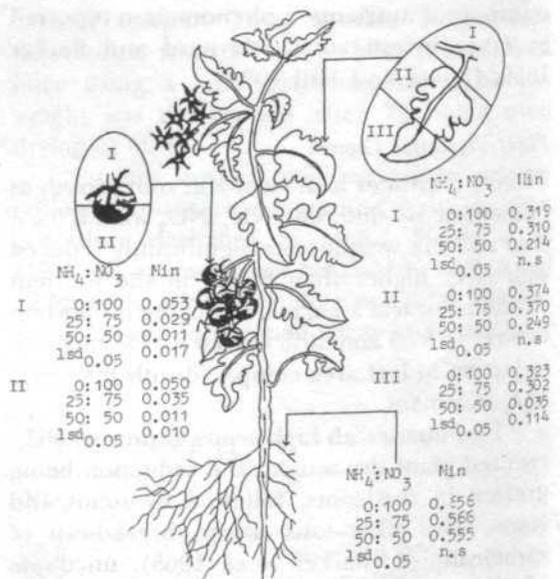


Fig. 3: Distribution of Ca in leaves, fruits and roots at week 5

TABLE 2

Leaf area, leaf, root and stem dry weight of tomato plants subjected to different NH₄⁺:NO₃⁻ ratios. T1=0:100 (pH adjusted to 6.0), T2=12.5:87.5, T3=25:75, T4=37.5:62.5, T5=50:50, T6=0:100; T2-T6 (pH not adjusted)

Treatment	Leaf area (cm ²)	Leaf	Dry weight (g/plant)		Root
			Stem		
T1	6309.30	40.2	32.6		21.7
T2	5933.00	38.8	31.1		20.0
T3	6061.30	38.6	28.9		20.1
T4	5252.50	36.6	29.3		18.5
T5	5110.30	38.1	29.7		20.6
LSD _{0.05}	761.20	1.9	ns		2.1

TABLE 3

Effects of NH₄⁺:NO₃⁻ ratio in the nutrient solution on fresh weight production of tomatoes

Treatment	Flower number (unit)	Fruit number (unit)	Fresh weight (g/plant)	% of BER	Fruit diameter (mm)	% dry matter	Total soluble solids (%)
T1	62	36	915.55	0	35.27	5.51	4.90
T2	62	34	886.35	2.57	34.15	5.37	4.97
T3	64	34	688.67	17.97	34.27	5.53	5.00
T4	60	33	623.91	24.37	34.65	5.48	5.05
T5	62	34	533.72	37.75	34.70	5.42	5.07
T6	61	36	857.42	2.72	34.70	5.30	4.72
LSD _{0.05}	ns	ns	118.12	4.35	ns	ns	ns

Means of 4 replication; NH₄⁺:NO₃⁻ ratio of; T1 & T6=0:100 (with and without pH controlled); T2=12.5:87.5; T3=25:75, T4=37.5:62.5 and T5=50:50; T2-T5 (without pH controlled)

Mineral Nutrition

Fig. 4-8 illustrate the partitioning of total N, P, K, Ca and Mg in different parts of the plant. In week 5, N concentration in young leaves and fruits generally increased with the concentration of NH₄⁺ in the solution (Fig. 4). Similarly, by week 12, increase in N ratio significantly increased N in all parts of the plant except in the stem. The percentage of P in the young leaves at both harvest dates increased with increase of NH₄⁺ in the N ratio (Fig. 5).

Changes in the percentage of P are associated with the mechanism of active uptake where anions such as P are present in higher concentration when NH₄⁺ is used as nitrogen source (Costellane *et al.* 1987). Similar mechanisms also apply when referring to K level (Fig. 6) in the plant parts where inorganic

cations such as K⁺ is depressed with increasing NH₄⁺ (Mengel and Kirkby 1982).

The effect of increasing the proportion of NH₄⁺ on Ca²⁺ at both harvest dates is illustrated in Fig. 7. Increasing the proportion of NH₄⁺ to more than 35% significantly reduced the percentage of Ca²⁺ in the young leaves at both harvest dates and in mature leaves, stems, roots and fruits at week 12. Pill *et al.* (1978) indicated that NH₄⁺ uptake must be accompanied by either inorganic anion uptake and/or higher organic anion production, or reduced uptake or inorganic cations. Furthermore, higher soluble salt concentration of substrate under NH₄⁺ nutrition may render divalent ions less available than monovalent ions. Our results showed that there were no significant differences (P>0.05) between treatments on Ca²⁺ level in roots when

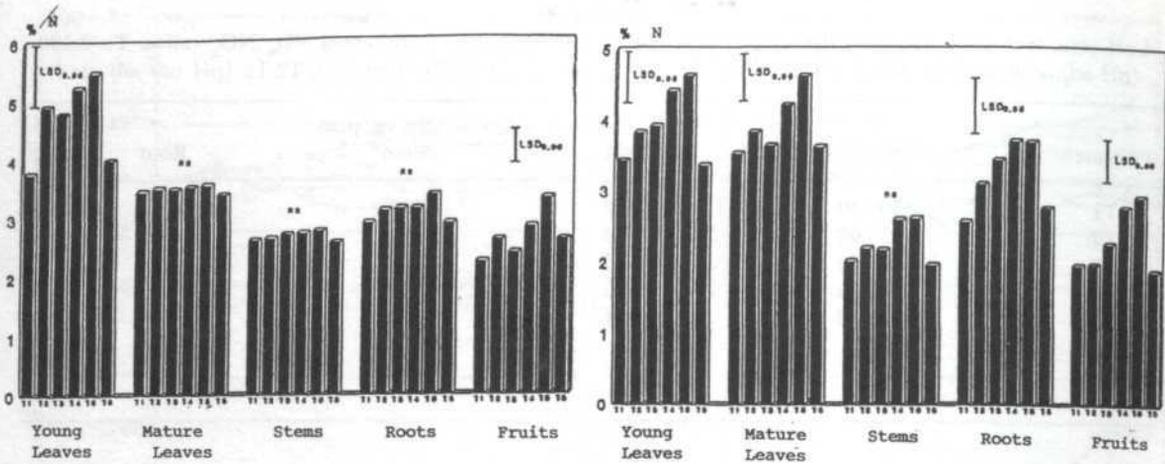


Fig. 4: Effects of NH₄⁺:NO₃⁻ ratio on the N content in various parts of the plant
a) week 5 b) week 12.

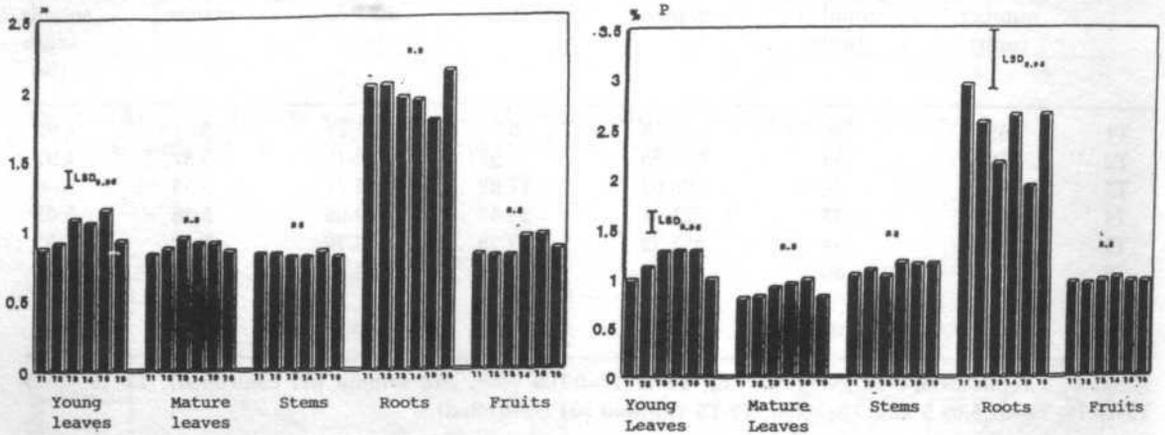


Fig. 5: Effects of NH₄⁺:NO₃⁻ ratio on the P content in various parts of the plant
a) week 5 b) week 12.

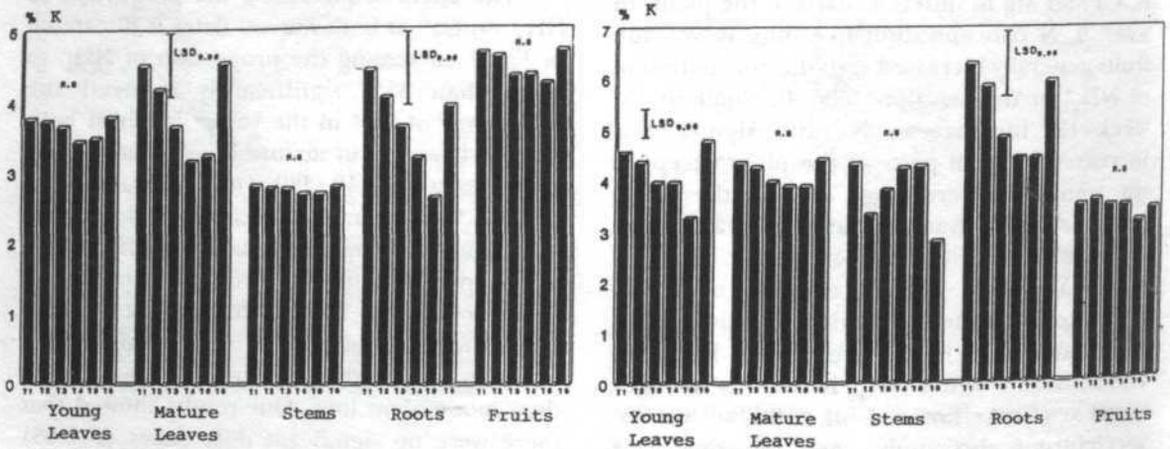


Fig. 6: Effects of NH₄⁺:NO₃⁻ ratio on the K content in various parts of the plant
a) week 5 b) week 12.

AMMONIUM (NH₄⁺): NITRATE (NO₃⁻) RATIO AND PLANT DEVELOPMENT

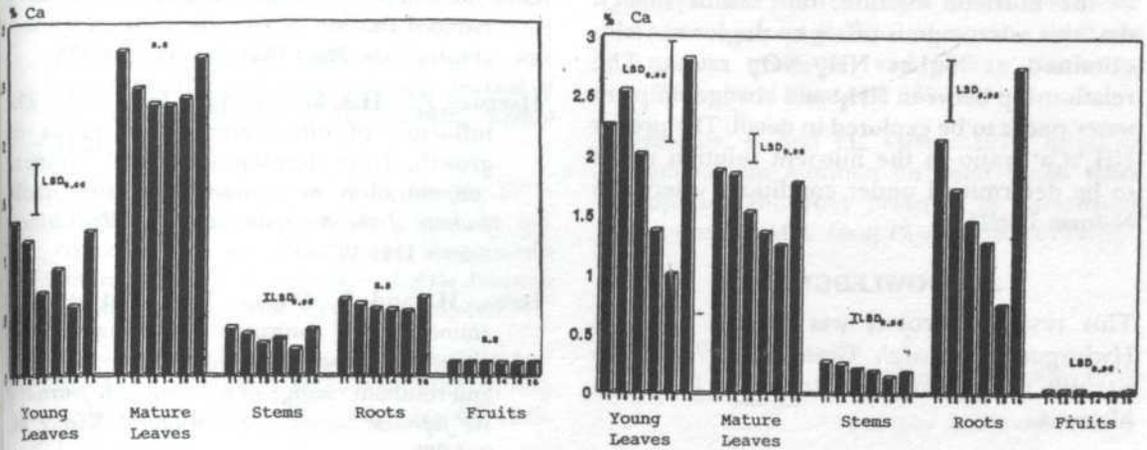


Fig. 7: Effects of NH₄⁺:NO₃⁻ ratio on the Ca content in various parts of the plant
a) week 5 b) week 12.

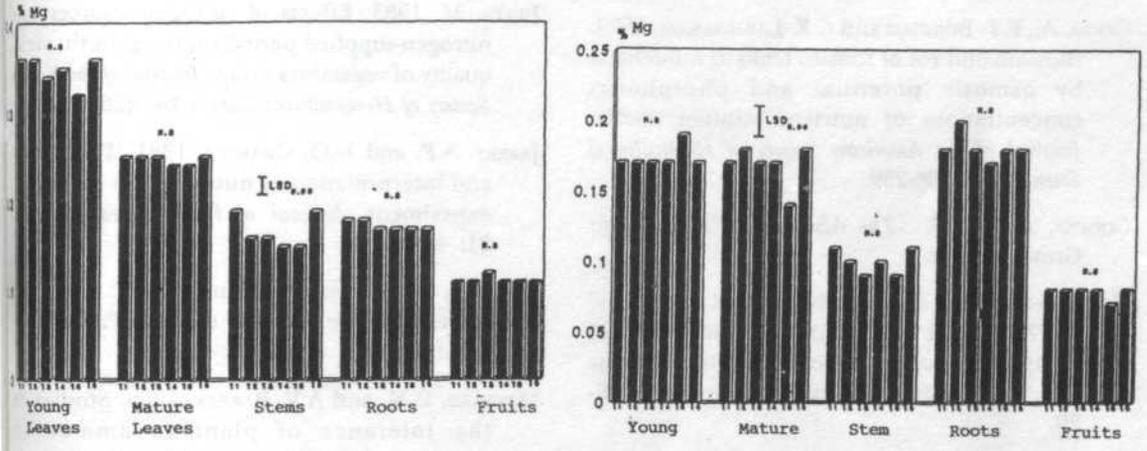


Fig. 8: Effects of NH₄⁺:NO₃⁻ ratio on Mg content in various parts of the plant
a) week 5 b) week 12

sampling was done in week 5. Evans and Troxler (1953) suggested that higher rates of organic acid synthesis as a result of NH₄⁺ may immobilize Ca⁺⁺ within the roots. However, sampling in week 12 saw Ca⁺⁺ levels significantly reduced with increased proportion of NH₄⁺.

The effect of the NH₄⁺:NO₃⁻ ratio on the percentage of Mg⁺⁺ was not pronounced except for mature leaves when sampled in week 12 (Fig. 8). Leaf Mg⁺⁺ decreased at the highest NH₄⁺:NO₃⁻ ratios. The mechanism of this reduction may be similar to those of Ca and K.

CONCLUSION

The reduction in plant growth with increase in the NH₄⁺:NO₃⁻ ratio could be due to the imbalance of nutrient uptake resulting from changes in the plant-water relationship. There was a clear increase in fruits with BER with increase of NH₄⁺ in the nutrient solution. Since the occurrence of BER is related to Ca⁺⁺ concentration, it may be necessary to increase application of Ca when fertilizer containing a high proportion of NH₄⁺ is used in order to reduce the severity of NH₄⁺ related BER. Although NH₄⁺ is useful in controlling pH level

in the nutrient solution, our results suggest that this advantage is offset by the lower yields obtained at higher $\text{NH}_4^+:\text{NO}_3^-$ ratios. The relationship between NH_4^+ and changes in plant water needs to be explored in detail. The proper $\text{NH}_4^+:\text{Ca}^{++}$ ratio in the nutrient solution needs to be determined under conditions where the N form is NH_4^+ .

ACKNOWLEDGEMENT

This research project was funded by IRPA Hydroponic Research Grant (50307) of the Faculty of Agriculture, Universiti Pertanian Malaysia.

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(Received 29 November 1993)

(Accepted 11 December 1995)