Ammonium (NH₄⁺): Nitrate (NO₃⁻) 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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ABSTRACT
The effects of NH₄⁺:NO₃⁻ ratio on growth, water uptake, solution pH, mineral nutrition and yield of tomatoes were investigated using the nutrient film technique. There were six NH₄⁺:NO₃⁻ 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 NH₄⁺:NO₃⁻ 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 NH₄⁺:NO₃⁻ in the solution. Increased ratio of NH₄⁺:NO₃⁻ increased N content and decreased Ca content in all the plant tissues. P, K and Mg content decreased in leaf tissue with increasing NH₄⁺:NO₃⁻ 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 (NH₄⁺) and/or nitrate ion (NO₃⁻). Cooper (1979), Iwata (1983) and Ikeda and Yamada (1984) reported that growth and plant development are enhanced by the use of NO₃⁻ 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 NH$_4^+$: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 NH$_4^+$:NO$_3^-$ treatments (Table 1)

The NH$_4^+$: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 NH$_4^+$: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>
<thead>
<tr>
<th>Treatment</th>
<th>NH$_4^+$</th>
<th>NO$_3^-$</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td>0</td>
<td>100.0</td>
<td>maintained at 6.0</td>
</tr>
<tr>
<td>T2</td>
<td>12.5</td>
<td>87.5</td>
<td>not controlled</td>
</tr>
<tr>
<td>T3</td>
<td>25.0</td>
<td>75.0</td>
<td>not controlled</td>
</tr>
<tr>
<td>T4</td>
<td>37.5</td>
<td>62.5</td>
<td>not controlled</td>
</tr>
<tr>
<td>T5</td>
<td>50.0</td>
<td>50.0</td>
<td>not controlled</td>
</tr>
<tr>
<td>T6</td>
<td>0</td>
<td>100.0</td>
<td>not controlled</td>
</tr>
</tbody>
</table>

**TABLE 1**

NH$_4^+$: NO$_3^-$ ratios of fertiliser used in nutrient film technique experiments on tomato
AMMONIUM (NH\(_4^+\)) : NITRATE (NO\(_3^-\)) RATIO AND PLANT DEVELOPMENT

RESULTS AND DISCUSSION

\(\text{pH of Nutrient Solution}\)

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 NH\(_4^+\):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 Coto 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 of influence NH\(_4^+\):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 Ozben (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 NH\(_4^+\):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 NH\(_4^+\):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 $\text{NH}_4^+:\text{NO}_3^-$ 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 $\text{NH}_4^+:\text{NO}_3^-$ ratios. $O=0.100$; $*=25:75$ and $\Delta=50:50$. 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.
AMMONIUM (NH\textsubscript{4}\textsuperscript{+}): NITRATE (NO\textsubscript{3}\textsuperscript{-}) RATIO AND PLANT DEVELOPMENT

### TABLE 2
Leaf area, leaf, root and stem dry weight of tomato plants subjected to different NH\textsubscript{4}\textsuperscript{+}:NO\textsubscript{3}\textsuperscript{-} ratios. T\textsubscript{1}=0:100 (pH adjusted to 6.0), T\textsubscript{2}=12.5:87.5, T\textsubscript{3}=25:75, T\textsubscript{4}=37.5:62.5, T\textsubscript{5}=50:50, T\textsubscript{6}=0:100; T\textsubscript{2}-T\textsubscript{6} (pH not adjusted)

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Leaf area (cm\textsuperscript{2})</th>
<th>Leaf</th>
<th>Dry weight (g/plant)</th>
<th>Root</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Leaf area (cm\textsuperscript{2})</td>
<td>Leaf</td>
<td>Stem</td>
<td>Root</td>
</tr>
<tr>
<td>T\textsubscript{1}</td>
<td>6309.30</td>
<td>40.2</td>
<td>32.6</td>
<td>21.7</td>
</tr>
<tr>
<td>T\textsubscript{2}</td>
<td>5933.00</td>
<td>38.8</td>
<td>31.1</td>
<td>20.0</td>
</tr>
<tr>
<td>T\textsubscript{3}</td>
<td>6061.30</td>
<td>38.6</td>
<td>28.9</td>
<td>20.1</td>
</tr>
<tr>
<td>T\textsubscript{4}</td>
<td>5252.50</td>
<td>36.6</td>
<td>29.3</td>
<td>18.5</td>
</tr>
<tr>
<td>T\textsubscript{5}</td>
<td>5110.30</td>
<td>38.1</td>
<td>29.7</td>
<td>20.6</td>
</tr>
<tr>
<td>LSD\textsubscript{0.05}</td>
<td>761.20</td>
<td>1.9</td>
<td>ns</td>
<td>2.1</td>
</tr>
</tbody>
</table>

### TABLE 3
Effects of NH\textsubscript{4}\textsuperscript{+}:NO\textsubscript{3}\textsuperscript{-} ratio in the nutrient solution on fresh weight production of tomatoes

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Flower number (unit)</th>
<th>Fruit number (unit)</th>
<th>Fresh weight (g/plant)</th>
<th>% of BER</th>
<th>Fruit diameter (mm)</th>
<th>% dry matter</th>
<th>Total soluble solids (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Flower number (unit)</td>
<td>Fruit number (unit)</td>
<td>Fresh weight (g/plant)</td>
<td>% of BER</td>
<td>Fruit diameter (mm)</td>
<td>% dry matter</td>
<td>Total soluble solids (%)</td>
</tr>
<tr>
<td>T\textsubscript{1}</td>
<td>62</td>
<td>36</td>
<td>915.55</td>
<td>0</td>
<td>35.27</td>
<td>5.51</td>
<td>4.90</td>
</tr>
<tr>
<td>T\textsubscript{2}</td>
<td>62</td>
<td>34</td>
<td>886.35</td>
<td>2.57</td>
<td>34.15</td>
<td>5.37</td>
<td>4.97</td>
</tr>
<tr>
<td>T\textsubscript{3}</td>
<td>64</td>
<td>34</td>
<td>688.67</td>
<td>17.97</td>
<td>34.27</td>
<td>5.53</td>
<td>5.00</td>
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<tr>
<td>T\textsubscript{4}</td>
<td>60</td>
<td>33</td>
<td>623.91</td>
<td>24.37</td>
<td>34.65</td>
<td>5.48</td>
<td>5.05</td>
</tr>
<tr>
<td>T\textsubscript{5}</td>
<td>62</td>
<td>34</td>
<td>533.72</td>
<td>37.75</td>
<td>34.70</td>
<td>5.42</td>
<td>5.07</td>
</tr>
<tr>
<td>T\textsubscript{6}</td>
<td>61</td>
<td>36</td>
<td>857.42</td>
<td>2.72</td>
<td>34.70</td>
<td>5.30</td>
<td>4.72</td>
</tr>
<tr>
<td>LSD\textsubscript{0.05}</td>
<td>ns</td>
<td>ns</td>
<td>118.12</td>
<td>4.35</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
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</table>

### 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 NH\textsubscript{4}\textsuperscript{+} 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 NH\textsubscript{4}\textsuperscript{+} 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 NH\textsubscript{4}\textsuperscript{+} is used as nitrogen source (Costellane et al. 1987). Similar mechanisms also apply when referring to K (Fig. 6) in the plant parts where inorganic cations such as K+ is depressed with increasing NH\textsubscript{4}\textsuperscript{+} (Mengel and Kirkby 1982).

The effect of increasing the proportion of NH\textsubscript{4}\textsuperscript{+} on Ca\textsuperscript{++} at both harvest dates is illustrated in Fig. 7. Increasing the proportion of NH\textsubscript{4}\textsuperscript{+} to more than 35% significantly reduced the percentage of Ca\textsuperscript{++} 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 NH\textsubscript{4}\textsuperscript{+} uptake must be accompanied by either inorganic anion uptake and/or higher organic anion production, or reduced uptake of inorganic cations. Furthermore, higher soluble salt concentration of substrate under NH\textsubscript{4}\textsuperscript{+} 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 Ca\textsuperscript{++} level in roots when

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Fig. 4: Effects of $\text{NH}_4^+:\text{NO}_3^-$ ratio on the $N$ content in various parts of the plant
a) week 5  b) week 12.

Fig. 5: Effects of $\text{NH}_4^+:\text{NO}_3^-$ ratio on the $P$ content in various parts of the plant
a) week 5  b) week 12.

Fig. 6: Effects of $\text{NH}_4^+:\text{NO}_3^-$ ratio on the $K$ content in various parts of the plant
a) week 5  b) week 12.
AMMONIUM ($NH_4^+$): NITRATE ($NO_3^-$) RATIO AND PLANT DEVELOPMENT

Young Leaves  Mature Leaves  Stems  Roots  Fruits

Fig. 7: Effects of $NH_4^+:NO_3^-$ ratio on the Ca content in various parts of the plant
a) week 5  b) week 12.

Young Leaves  Mature Leaves  Stems  Roots  Fruits

Fig. 8: Effects of $NH_4^+:NO_3^-$ 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 $NH_4^+$ may immobilize $Ca^{++}$ within the roots. However, sampling in week 12 saw $Ca^{++}$ levels significantly reduced with increased proportion of $NH_4^+$.

The effect of the $NH_4^+:NO_3^-$ 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 $NH_4^+:NO_3^-$ 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 $NH_4^+:NO_3^-$ 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 $NH_4^+$ 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 $NH_4^+$ is used in order to reduce the severity of $NH_4^+$ related BER. Although $NH_4^+$ 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 NH$_4^+$:NO$_3^-$ ratios. The relationship between NH$_4^+$ and changes in plant water needs to be explored in detail. The proper NH$_4^+$:Ca$^{++}$ ratio in the nutrient solution needs to be determined under conditions where the N form is NH$_4^+$.

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