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The effects of potassium on ammonium nutrition in tomato (Lycopersicon esculentum, mill., Heinz 1350).
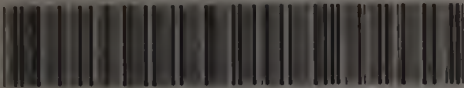
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THE EFFECTS OF POTASSIUM ON AMMONIUM NUTRITION

IN TOMATO (LYCOPERSICON ESCULENTUM, MILL.,

HEINZ 1350)

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DEFINITION OF PROBLEM

A great deal of work has been done by scientists to determine the functions of nitrogen in plants, since the first concrete proposal of its essentiality was reported by De-Sausseur in 1804. Nitrogen can be applied to the soil for plant use in a variety of forms, i.e., nitrate, ammonium and organic (15).

In practical farming, the application of the nitrate and organic forms are relatively expensive. Recently, the availability of nitrogen in the inexpensive ammonium form has generated considerable interest and has become very popular among farmers. For example, approximately 80 per cent of the fertilizer nitrogen used is in the ammonium form (68). However, it has been found that the prolonged fertilization or absorption of ammonium salts causes ammonium toxicity in most cultivated plant species (42, 43, 45).

Potassium is very important in the regulation of nitrogen metabolism. It influences the amounts of protein and soluble nitrogenous compounds present in the plants (8, 33, 66) and also restricts plant injuries caused as a result of ammonium toxicity (7, 9, 32).

It is the aim and purpose of this thesis to determine the possibility of recovery from ammonium toxicity, i.e., the healing of stem lesions by supplemental potassium in the tomato plant (Lycopersicon esculentum; Heinz 1350). Experiments were also conducted to determine the extent of lesion development which occurred before the damage was irreversible.

REVIEW OF LITERATURE

History of the Tomato Plant

The tomato is a native of tropical America and is reported to
have been eaten by the native tribes of Mexico, who called it "tomati"
(67). It is one of the most important and popular vegetables grown
in the world and the first known record of it as a plant was made by
Matthiolus in Italy in 1554 (67).

Taxonomy

The tomato belongs to the nightshade or Solanaceae family and
the genus Lycopersicon. It is a herbaceous plant, annual where frost
occurs and perennial in the tropics. The stems are round, soft,
brittle and hairy when young, but become angular, hard and almost
woody when old. The leaves are alternate and glandular, secreting
greenish yellow juice. The flowers occur in clusters along the stem
between the nodes. The fruit is a two- to many-celled berry with
fleshy placentae and many hairy, kidney-shaped seeds. The root system
is wide and deep, lacking extended tap root. It is self-pollinated.
Two distinct species, Lycopersicon esculentum and Lycopersicon
pimpinellifolium are generally recognized by most authorities with
five varieties listed under the former (67).

The tomato is a warm-season crop and is sensitive to frost. High
humidity with high temperature favors the development of foliage diseases.
Hot drying winds often cause the dropping of the blossoms, but irriga-
tion will lower the temperature, raise the humidity and prevent much of
the blossom drop (77). Tomatoes grow on nearly all kinds of soils from

light sand to heavy clays and can tolerate fairly acid soils (80). For
high production, it is essential that the soil be well-drained and
retentive of moisture.

Tomato Production in the United States

Tomatoes are produced commercially in almost every state in the
United States, with Florida and California ranking first, as the most
important producers for the fresh market (68). In 1965, Massachusetts
ranked first in New England with a yield of 185 cwt per acre followed
by Rhode Island with 165 cwt per acre and Connecticut with 140 cwt (74).

Tomato Diseases

Generally, the diseases are of two types - parasitic and
non-parasitic (70). Unfavorable environmental conditions, such as
excessive moisture or drought, extremes of temperature, and lack or
excess of certain mineral elements in the soil may cause the
non-parasitic disease. The parasitic diseases are caused by living
organisms, such as bacteria, fungi and viruses, and they are the most
serious (70).

Blossom-end rot, a non-parasitic disease is a physiological
disorder of tomato fruits (17, 42, 50, 57). Some of the symptoms are
the appearance of dark, irregular, watersoaked areas at or near the
blossom-end of the fruit, followed by the coalescing of these discolor-
ations to form a depressed, leathery area at the blossom-end. Fruits
are more frequently affected at the immature green stage.

Some of the factors causing blossom-end rot disease are
unfavorable weather conditions, (17, 44, 57) high osmotic pressures of
nutrient solutions (42, 50), applications of fertilizers high in K^+ and

NH_4^+ (17, 42, 50, 57, 69), and insufficient amount of Ca^{++} (17, 42, 50, 57). Satisfactory control of blossom-end rot lies in the adequate supply of Ca^{++} and the avoidance of excesses of K^+, NH_4^+ and Mg^{++} fertilizers.

Forms of Nitrogen Supplied by Fertilizers

The increase in the use of nitrogen fertilizers has enhanced the production of agricultural crops, by increasing yields with reduced use of land and manpower. The bulk of the nitrogen used by plants is in the combined forms of ammonia, ammonium ions, nitrate and amine (15). Anhydrous ammonia supplies nitrogen as gaseous ammonia (NH_3), while ammonium sulfate, aqua ammonia, ammoniated solutions and ammonium nitrate supply ammonium ion (NH_4^+) (23). The nitrate ion (NO_3^-) is supplied by nitrate salts, e.g., KNO_3 and the amine form is supplied by urea (15, 23).

Black (15) discussed two methods by which nitrogen fertilizers could be incorporated into the soil, i.e., by direct application and indirect application by cultivation operations. Anhydrous ammonia and ammonium hydroxide are usually placed below the soil, because of the volatility of ammonia. Solid nitrogen fertilizer is applied to the surface of the soil and urea may be absorbed by the foliage after spraying.

Forms of Nitrogen in the Soil

Elemental nitrogen is present in the soil in three main forms; gaseous, inorganic and organic. Nitrous oxide (N_2O), nitric oxide (NO), nitrogen dioxide (NO_2), and ammonia (NH_3) are the gaseous forms, and ammonium (NH_4^+), nitrite (NO_2^-) and nitrate (NO_3^-) are the inorganic

forms in which nitrogen exists in the soil (23). The organic nitrogen
is largely proteinaceous, (60) and is derived from plant and animal
residues.

Some effects of nitrogen fertilizers on the soil pH have been
reported. Donald et al. (23), observed that ammonia and aqua ammonia
application to the soil raises the pH in the area of application,
because they are basic. On the other hand, the application of ammonium
nitrate, calcium nitrate and sodium nitrate have little immediate effect
on pH, because they are neutral salts. pH of the soil varies with
different nitrogen carriers (23). Nitrogen carriers containing
metallic cations either increase or have a neutralizing effect on
acidity, while those carriers with NH_4^+ as the cations lower the pH,
an example of which is ammonium sulfate, which carries the acidic
sulfate radical.

Forms of Nitrogen Absorbed by Plants

It is generally known that nitrogen occurs in both inorganic and
organic forms in plants. The organic forms predominate over the
inorganic (15). Nitrate is absorbed by plants as an inorganic form,
assimilated by reduction to ammonium, and later incorporated into the
organic forms. Most of the organic nitrogen is present in the form of
protein (60), which includes enzymes (15).

Nitrogen deficiency results in a reduction in leaf size and the
number of lateral shoots (23), stems are thin and there is a general
reduction in plant growth. Leaves have a pale-green color due to a
reduction in chlorophyll content (49), with older leaves often becoming
yellow - a condition associated with severe proteolysis (35, 49).

Worsening conditions may bring about a predominance of anthocyanin pigments, which are usually present in the petioles and veins of tomato plants (35).

Functions of Ammonium-nitrogen in Plants

As earlier stated, the ammonium ion constitutes one of the most important sources of nitrogen utilized by plants. Experiments with a number of plant species have shown that ammonium exerts a pronounced effect on both the growth and chemical composition of plants, when supplied as a nitrogen source (3, 9, 13, 20, 44, 79).

Working with tobacco plants and using isotopic $N^{15}H_3$, Vickery et al. (75), demonstrated the incorporation of ammonia into amides, amino-acids and proteins. Similar findings were reported by Cocking et al. (20) with barley seedlings, and also Austin (3), working with nitrogen starved wheat seedlings. Syrett (63) observed that the basic amino acids (arginine, lysine, and ornithine), represented a large proportion of the free amino acids, formed in the first stage of ammonia assimilation in Chlorella vulgaris. Deficiency and excess amounts of ammonium-nitrogen were found to increase the amino-acid contents, (aspartic acid, arginine and histidine) in the tops of soybean plants, while in the roots, the amino-acid contents increased with increases in the nitrogen concentrations in the root medium (32).

Studies conducted by Maynard et al. (9, 44) linked some severe tomato injuries, with the accumulation of ammonium in their tissues. Barker et al. (13) noted that bean plants were just as sensitive to ammonium nutrition. William et al. (79) showed that a heavy fertilization of ammonium salts in orchard grass could cause a stress in their

metabolism, by causing an accumulation of asparagine, while reducing the potassium content below 1.5 per cent of the dry weight.

One of the direct results of ammonium accumulation is ammonium toxicity. Ammonium toxicity is caused by the prolonged fertilization or absorption of ammonium salts, as a source of nitrogen by most plant species. (9, 13, 44). It results in chlorosis, restricted growth and in some cases, the death of the plant. In tomato plants one of the chief morphological symptoms of ammonium toxicity is the development of stem lesions (9, 44), spreading to the petioles and leaf-blades upon continuous ammonium application.

Anatomically, Barker et al. (10) showed that cellular injury localized within the epidermal and cortical regions of the affected stems appeared evident, while the vascular and pith tissues remained intact. Damaged cells showed evidence of cellular collapse and thickening of the cell walls.

Physiologically, there is a high accumulation of soluble nitrogenous compounds, including considerable amounts of inorganic ammonium in tomato plants, under ammonium toxicity conditions (9, 44). Barker et al. (13) noted similar effects of ammonium toxicity in bean plants.

Uljee (73) observed the greatest incidence of root rot and corkiness in tomato roots, when ammonium application was highest. He suggested that ammonium accumulation could be a possible cause of corkiness or root rot in tomatoes, or could provide conditions suitable enough for the successful invasion of the roots, by soil-borne organisms.

Other deleterious effects have been observed in protein synthesis, photosynthesis, respiration and carbohydrate metabolism. Yemm and

Willis (81) and later Barker et al. (14) suggested a decline in protein synthesis along with an increase in soluble nitrogen compounds, possibly due to proteolysis. In concentrations of 0.6mM., ammonium ions inhibited ATP formation by 50 per cent (39) and also caused a reduction in CO_2 fixation within the chloroplast (71). With ammonium accumulation, chlorophyll loss and a decrease in photosynthesis were observed in the leaves (49).

Many workers (4, 5, 12) have studied the effects of the addition of ammonium salts to nitrogen-starved algae and higher plants. Increases were found in the respiratory ratio of such tissues. (29, 34, 63). Continuous supply of ammonium brings about reactions which incorporate ammonium into organic compounds at the expense of other vital growth processes such as protein and cell-wall syntheses (4). Carbohydrate and metabolic energy may therefore be diverted to the synthesis of nitrogenous storage compounds, such as amides (4).

Evidence of the effect of ammonium ion on the absorption of other ions has also been noted (30, 37, 41, 48). Prianishnikov (48), concluded that the inadequacy of ammonium fertilizers was due to their strongly acidic nature, and Gouny (30) in his work agreed that H^+ ions generated during ammonium uptake competed directly with other cations for absorption by plant roots. Kirby, (37) working with white mustard plants observed that plants supplied with ammonium-nitrogen generally did not grow well and contained lower concentrations of inorganic cations such as Ca^{++}, Mg^{++} and K^+, and higher concentrations of anions, such as sulfate, phosphate and chloride, when compared with tissues supplied with nitrate-nitrogen. MacLeod and Carson, (41) noted that under high ammonium source and low K^+, there was a depression in yield,

reduction in tillering and significant changes in the per cent K^+, Ca^{++}, Mg^{++} and P in grasses.

One of the environmental factors that govern the utilization of ammonia by plants is pH. High pH favors the uptake of ammonia (2). Wall (76) reported that the injuries in tomato leaves became much worse under K^+ deficient conditions and when the pH was below 6.0. Sheat et al. (56) concluded that ammonium served as an effective nitrogen source for the growth of excised tomato roots, only when acidity was maintained in the range of pH 6.8 - 7.4. Barker (7) agreed with this concept and showed an increased incorporation of ammonium into organic compounds in the roots of bean plants, under neutral conditions.

The age of the plant also influences nitrogen assimilation (16, 65). Thus rice (16) and similarly wheat and oat seedlings (65) assimilate ammonia better than nitrate when young, and later attain the ability to assimilate nitrate equally well upon maturation.

The ability to utilize ammonium as a source of nitrogen varies among different plant species (19). Very few species develop better on ammonium nutrition than on nitrate nutrition (78). The ericaceous plants (blueberries, rhododendrons) are well-known in this respect (19, 22). Cain (19) and Colgrove et al. (22) pointed out that these plants often became chlorotic on nitrate nutrition and under alkaline culture conditions. On the other hand, ammonium nutrition would permit their normal growth. Ericaceous plants seem to thrive in acidic soils and their survival is apparently related to their ability to use ammonium nitrogen in an acidic environment (19, 22). Within species, plants are known to differ with respect to ammonium tolerance. The

resistance of certain tomato varieties to stem lesions illustrated an example of variation within species (45).

Potassium has been recognized as an essential plant requirement for over 100 years. It is one of the most important macronutrients and is present in greater quantity than any other inorganic ions in plants, with the possible exceptions of nitrogen and hydrogen (15).

Forms of Potassium In Soils

Potassium is widely distributed in the soil and most of it is present in the mineral forms of feldspar and mica (54). The most important of these mineral forms are the orthoclase and microline feldspars, the biotite and muscovite micas and the micaceous clays called illite (54). All of these minerals occur in the sand, silt and clay fractions of the soil (15). Chemically, the soil potassium is classified into three groups -- nonexchangeable, exchangeable and water-soluble (18).

On the basis of solubility, Black (15), categorized the K^+-bearing minerals into two groups, one group with moderate to high solubility in water and another with extremely low solubility. The low solubility group includes principally the feldspars and micas. Although, they contain considerable amounts of K^+, they must be treated in order to increase K^+ solubility for fertilizer purposes (15). However, the cost of treatment makes their use uneconomical in comparison with the soluble minerals (15). The potassium sources used in fertilizer production are soluble salts (18).

Forms of Potassium Supplied by Fertilizers

Potassium is supplied to the soil as fertilizer such as muriate

of potash (KCl) which contains 51 per cent of water-soluble K^+ (58).

Other K^+ fertilizers are potassium sulfate, (44.87 per cent K^+)

potassium-magnesium sulfate (18.26 per cent K^+), potassium phosphate

(33.09 per cent K^+) and potassium nitrate (38.66 per cent K^+) (15, 58).

Potassium Movement in the Plant

With reference to the distribution of potassium in plants, K^+ is

found in the individual cells, most commonly in the vacuole and

cytoplasm (62). It is very mobile and therefore, readily redistributed

under stress conditions (62). Generally, potassium is transported to

the metabolically active portions - young buds, root-tips and young

shoots, of the plants (6), hence its deficiencies are first noticed in

the older portions (35). Due to its mobility and the fact that it

exists as free ions (58), the determination of its location in plants is

difficult.

Potassium has been indicated to be absorbed both passively and

actively by plant roots (25, 26, 62). Passive absorption, which is

non-metabolic and reversible consists of diffusion of ions into the free

space of the cell-wall, and the exchange of K^+ cation for the cations

held on the root surface (26, 58, 62). Active uptake, which makes use

of metabolic energy (25, 26, 62) is irreversible and requires ion-bind-

ing compounds called carriers (21, 25, 26). The carrier combines with

the K^+ at the root surface, transports it through the plasma membrane,

and then releases it inside the cell (58, 62).

There is selectivity in the nature of the ion uptake process, and

this has been attributed to the types of carriers which are present on

the root, during the transport of the ions into the plant (27, 62).

Working on excised root, Epstein and Hagen (27) showed that K^+, Rb^+ and Ca^+ competed for the same carriers, while Na^+ and Li^+ did not compete for these sites.

Some of the important functions of K^+ in agronomic crops are in increasing the yields of corn, alfalfa, sugar-cane, soybeans, and other crops (32), improving the quality of sugarbeets and sugar-cane (55), decreasing the amount of lodging in corn (38), and increasing disease resistance in peanut (24), and Bermuda-grass (1).

Functions of K^+ in Plant Metabolism

The physiological functions of K^+ in plants are various (28, 31, 64, 72). Although some important roles in plant metabolism have been attributed to it, some doubt still exists as to the exact mechanism in which it is involved (8). Potassium is essential for the activity of the enzyme pyruvic kinase, which is responsible for the transformation of carbohydrate intermediates (28). Gregory and Richards (31), found that K^+ deficiency increased the rate of respiration in barley leaves, and decreased their rates of photosynthesis, resulting in a depressed rate of dry matter production. Barker et al. (13) reported similar findings in mature bean leaves, but associated the depression in photosynthesis, with chlorophyll degradation as well as potassium loss from the tissue. As a result of the increased respiration and decreased photosynthetic rates, carbohydrate depletion (21, 61) and reduction in growth rates (47, 66) were observed in potassium deficient plants.

Potassium plays a chief role in the regulation of nitrogen metabolism. Plants deficient in potassium usually contain a lower protein content (33, 52, 61, 66) and higher amounts of soluble nitrogenous

compounds, like amino-acids, (52, 72) and amides (47, 64), than those adequately supplied with K^+. Richards and Templeman (53) suggested that proteolysis might occur more rapidly in K^+ deficient plants, and that this might account for the high amino-acid and amide contents of such plants. Barker et al. (13) arrived at a similar conclusion in bean plants, and that proteolysis accounted for 60 per cent of the accumulating free amino-acids when ammonium was supplied as the nitrogen source. Accumulation of these soluble nitrogenous constituents was accentuated under K^+ deficiency (13, 52).

The production of toxic amines under conditions of potassium stress in wheat and barley plants was reported by Coleman and Richards (21). It was evident that normal nitrogen metabolism was severely affected, and also that putrescine was produced. The production of putrescine was enhanced in the presence of ammonium ions.

Severe injury found under conditions of ammonium toxicity was reduced in the presence of K^+ (51). Increased accumulation of total and soluble nitrogen content of tomato plants decreased with increases in K^+ concentrations, (49), thus lessening the chances of ammonium toxicity. This result was also supported by the work of MacLeod and Carson (41), who found that the total-protein, non-protein and nitrate-N in alfalfa, bromegrass, orchard-grass and timothy-grass grown in soil culture decreased with increasing concentration of K^+.

MATERIALS AND METHODS

Preliminary experiments were conducted in the spring of 1968, and factorial experiments were conducted in 1969 with tomato plants (Lycopersicon esculentum, Mill e.v. Heinz 1350) in the greenhouse in order to achieve the following objectives:

1. To study the effects of potassium on ammonium accumulation and the development of ammonium toxicity symptoms manifested by stem lesions with time.

2. To determine the possibility of recovery from ammonium toxicity i.e., the healing of stem lesions by supplemental potassium application, and to determine the extent of lesion development which must occur before damage is irreversible.

The tomato plant was used because of its rapid development of stem lesions when supplied with ammonium-nitrogen. This is a manifestation of its susceptibility to ammonium toxicity (45).

Greenhouse Culture Technique

1. Time Study on Ammonium Accumulation

Soil culture: Experiment I. - Eight-week old tomato plants were transplanted from flats to six-inch clay pots filled with a mixture of soil, peat, and sand mixed in the ratio of 7:3:2. Treatments were initiated two weeks after transplanting on March 13, 1969. Each treatment was replicated four times; each pot represented a single-plant plot.

The plants received solutions of $0.08N$ $(NH_4)_2SO_4$ with concentrations of potassium at 0, 0.04N, and 0.08N KCl applied to the soil surface at the rate of 250 ml. per pot daily for 24 days. Plants were

harvested at 0, 4, 8, 12, 16, 20 and 24 days respectively after application of the treatments.

The fresh weights of the plant shoots were taken and the incidence of stem lesions was noted using 0-3 scale, i.e., 0 - no lesion; 1 - slight; 2 - moderate; and 3 - severe. The pH of the soil samples before and after the conclusion of the experiment was also recorded.

Soil Culture: Experiment II. - Eight week-old tomato plants were transplanted from flats to six-inch clay pots, filled with a mixture of soil, peat and sand mixed in the ratio of 7:3:2, as in the previous experiment. Treatments were initiated on March 13, 1969, two weeks after transplanting. Each treatment was replicated four times; each pot represented a single-plant plot.

The plants received equinormal concentrations of ammonium sulfate and potassium chloride at 0, 0.01N, 0.02N, 0.04N, and 0.08N, at the rate of 250 ml. per pot daily for a period of three weeks. Plants were harvested at 0, 7, 14 and 21 days after the application of treatments.

The fresh weights of the plant shoots were noted and the incidence of stem lesions was recorded using the 0-3 scale. The pH of the soil samples before and after the conclusion of the experiment was recorded.

2. Ammonium Reversibility

Sand culture: Experiment I. - Seven-week old tomato plants were transplanted from flats to six-inch plastic pots, containing approximately 1,000 gms. of 1:1 mixture of fine and coarse pure quartz sand. In one aspect of this experiment designed to show the effect of liming on lesion formation, two groups of these plants were transplanted to pots of sand containing 10 gm. (10 tons/acre) of limestone (28.5 per

cent Ca^{++} and 4.5 per cent Mg^{++}) per pot. The resulting pH was 6.9.

On November 20, 1968, all the plants were treated with normal Hoagland's solution (36) - 250 ml./ plant daily for a period of two weeks. This treatment was replaced with a modified Hoagland's solution containing 0.02N $(NH_4)_2SO_4$ and applied at 250 ml per pot daily, until slight severity (No. 1 rating) lesions were developed. Later, treatments to reverse this effect of ammonium were commenced with the application of Hoagland's solution modified with additions as follows:

1. 0.02N KCl at 250 ml per pot daily.

2. 0.02N KCl at 250 ml per pot daily + $CaCO_3$.

3. One application of 10-g $CaCO_3$ + 250 ml of deionized water per plant daily.

4. 0.02N KCl + 0.02N $(NH_4)_2SO_4$ at 250 ml per plant daily.

5. 0.02N $(NH_4)_2SO_4$ at 250 ml per plant daily. (Control).

Each treatment was replicated four times with each pot representing a single-plant plot.

The experiment was carried out for three weeks and plants were harvested at 0, 7, 14 and 21 days respectively, after the initiation of treatments at the various K^+ levels. The fresh weights of the shoots just before and during the treatments were recorded. The disappearance of lesions was also observed.

Composition of Nutrient Solution

Nutrients	Concentration
$CaCl_2$	.10.0 meq/l
$MgSO_4$	4.0 meq/l
KH_2PO_4	1.0 meq/l
$NaNO_3$	5.0 meq/l
KNO_3	5.0 meq/l
Iron	1.0 ppm
Minor elements (Hoagland and Arnon (36))	. 1.0 ml

Modified Hoagland's (NH_4^+) Solution

Nutrients	Concentration
$CaCl_2$	.10.0 meq/l
$MgSO_4$	4.0 meq/l
NaH_2PO_4.	1.0 meq/l
$(NH_4)_2SO_4$.	.20.0 meq/l (0.02N)
Iron	1.0 ppm
Minor elements (Hoagland and Arnon (36)).	. 1.0 ml

Modified Hoagland's (K^+) Solution

Nutrients	Concentration
$CaCl_2$	10.0 meq/l
$MgSO_4$	4.0 meq/l
NaH_2PO_4	1.0 meq/l
KCl	20.0 meq/l
Iron	1.0 ppm
Minor elements (Hoagland and Arnon (36)) .	1.0 ml

Soil culture: Experiment II. - Eight-week old tomato plants

first grown in flats were later transplanted to six-inch clay pots

containing a mixture of soil, peat and sand mixed in the ratio of

7:3:2. Treatment with 0.04N $(NH_4)_2SO_4$ at the rate of 250 ml per plant

was applied until lesions were formed at the 1, 2 and 3 degrees of

severity. On October 4, 1968, this treatment was replaced with the

following treatments, at the rate of 250 ml per plant daily:

1.   0.04N KCl

2.   0.04N KCl + 0.04N $(NH_4)_2SO_4$

3.   Deionized water

4.   0.04N $(NH_4)_2SO_4$ (Control)

This application was continued for a three-week period and plants were

harvested at 0, 7 and 14 days respectively after the application of

the above-mentioned treatments. Each treatment was replicated four

times.

The fresh-weights of the shoots at lesion formation and also

during the application of treatments to reverse this effect were

recorded, and the appearance of lesions was observed.

Analytical Procedures

Ten gram samples of fresh leaf materials from each treatment of the experiments on the time study of ammonium accumulation and ammonium reversibility were selected and stored at -20°C until they could be prepared for analyses.

The samples were homogenized in 70% ethanol and extracted several times, using suction filtration. The extract was evaporated to dryness under the hood, and then dissolved in 70% ethanol with small amounts of chloroform, in order to facilitate solution. This was transferred into Kjeldahl flasks, evaporated under a stream of air and later analyzed for ammonium-nitrogen, and amide-nitrogen (measured in mg/g fresh weight), using the modified Kjeldahl method (11).

The remaining fresh samples of the leaves and petioles of the shoots were oven-dried at 80°C. These dried samples were then ground in Wiley Intermediate Mill, using a 20-mesh screen. A 200 mg dry-weight sample was analyzed for total-nitrogen (measured in per cent dry-weight), using a Micro-Kjeldahl method (19). One-hundred milligrams was weighed and digested using $HNO_3-H_2O_2$ procedure described by Lagerwerff and Peech (40).

The digested solutions were quantitatively transferred to 25 ml volumetric flask with distilled water. The solution was further diluted 1:50 prior to K^+ determination, using the Perkin-Elmer 290 Atomic Absorption Spectrophoto-meter.

Soil pH was measured by placing 50 g of soil or sand into a beaker and adding 50 ml of 0.01M $CaCl_2$. After stirring the mixture

thoroughly, the pH of the supernatent was measured using a Beckman

Expandomatic pH meter.

Statistical analyses of variance, and Duncan's multiple range

tests for all the experiments were performed by the methods described

by Steel and Torrie (59). A complete partitioning of treatment factors

and interactions have been calculated in all analyses but only the

Duncan's multiple range tests are reported therein.

RESULTS

Experiment 1. The Effects of K^+ on the
Occurrence of Ammonium Toxicity and
on Plant Composition

The results of a greenhouse soil experiment designed to show the effects of concentrations of K^+ with time on ammonium nutrition are shown in Table Ia - If.

Stem Lesions

Ammonium toxicity, as measured by the severity of stem lesions, (Figure 1) was evident four days after the initiation of treatments and was severe after twelve days, when $(NH_4)_2SO_4$ was supplied alone (Table Ia). Stem lesions also appeared after four days, when K^+ was supplied at 0.04N, but the severity did not increase greatly with time. The occurrence of stem lesions was completely prevented for the entire duration of the experiment, when K^+ was supplied at 0.08N (Table Ia).

Fresh Weight

Growth, as measured by the fresh weight of tomato shoots (Table Ib), was not enhanced with time, when 0.08N $(NH_4)_2SO_4$ was supplied alone. Substantial growth was observed however, when K^+ was supplied at 0.04N and 0.08N from eight days to twenty-four days after the initiation of treatments. There was no significant difference between the 0.04N and 0.08N K^+ treatments with time.

NH_4^+-N

There was a significant increase in the concentration of NH_4^+-N in tomato leaves with time (Table Ic) when NH_4^+ was supplied to the

Figure 1. Normal tomato stem (right) and tomato stem
showing ammonium-induced lesions (left).

plants without K^+. Although, the concentration of NH_4^+-N increased significantly with time at 0.04NK^+, there was a lower NH_4^+-N concentration twenty-four days after the initiation of treatments, when compared to the 0.08N $(NH_4)_2SO_4$ treatment.

Amide-N

Significant increases in the amide-N concentration occurred in four days, after the initiation of treatment with 0.08N $(NH_4)_2SO_4$. Amide-N concentrations at 0.04N K^+ and 0.08N K^+ treatments also showed substantial increases with time, but these concentrations were significantly lower than those obtained with the 0.08N $(NH_4)_2SO_4$ treatment, in the absence of K^+.

Total-N

The absence of K^+ enhanced the percentage of total-N in the leaves of tomato plants supplied with NH_4^+, with time (Table Ie). Smaller increases in the total-N concentrations were observed with 0.04N and 0.08N K^+ treatments, than with 0-K^+; the percentage total-N was least in the 0.08N K^+ treatment.

Potassium

The K^+ concentrations in the leaves of tomato plants treated with 0.08N $(NH_4)_2SO_4$ alone (Table If), showed a sharp decline after four days, and then declined more slowly, until the conclusion of the experiment. The 0.04N K^+ treatment slowly increased the K^+ concentration of the leaf tissue, throughout the experiment. At 0.08N K^+ more rapid increases in K^+ concentration were observed.

Soil pH

The pH of the soil samples (Table Ig) treated with 0KCl, 0.04NKCl

and 0.08NKCl in the presence of 0.08N $(NH_4)_2SO_4$, decreased in 4 days,

but remained constant 8, 12, 20 and 24 days after the application of

treatments. There was a general decrease in the soil pH in all three

treatments 16 days after treatments. The soil pH of all three treat-

ments showed no significant differences when compared with one another.

TABLE 1a

EFFECTS OF K^+ TREATMENTS ON THE DEVELOPMENT

OF AMMONIUM TOXICITY, AS EVIDENCED BY STEM

LESIONS, IN TOMATOES GROWN ON

0.08N $(NH_4)_2SO_4$ IN SOIL

| | KCl Concentration | | |
Days	0	0.04N	0.08N
Stem Lesion Rating (o; none - 3; severe)			
0	0a	0a	0a
4	1.75c	1.00b	0a
8	2.00c	1.00b	0a
12	3.00d	1.00b	0a
16	3.00d	1.00b	0a
20	3.00d	1.00b	0a
24	3.00d	1.75c	0a

Means within a sub-table followed by the same letter are not significantly different at the 5 per cent level of probability.

TABLE Ib

EFFECTS OF K^+ TREATMENTS ON GROWTH, AS

MEASURED BY THE FRESH WEIGHT OF

TOMATO SHOOTS GROWN ON

0.08N $(NH_4)_2SO_4$ IN SOIL

| Days | KCl Concentration | | |
| | 0 | 0.04N | 0.08N |
	Fresh Weight of Plant Shoot (gms)		
0	29.8a	29.8a	29.8a
4	37.0ab	38.8ab	29.5a
8	49.0ab	54.2b	41.5ab
12	50.9ab	61.0bc	64.0bc
16	52.0ab	72.2bc	71.8bc
20	47.8ab	85.3c	78.5c
24	36.5ab	90.5c	84.7c

Means within a sub-table followed by the same letter are not significantly different at the 5 per cent of probability.

TABLE Ic

EFFECTS OF K^+ TREATMENTS ON THE AMMONIUM-N

CONCENTRATION IN TOMATO LEAVES GROWN

ON 0.08N $(NH_4)_2SO_4$ IN SOIL

Days	KCl Concentration		
	0	0.04N	0.08N

Ammonium-N concentration of plant leaves
(mg/g fresh weight)

Days	0	0.04N	0.08N
0	0.03a	0.03a	0.03a
4	0.17ab	0.09ab	0.12ab
8	0.54cd	0.34bc	0.19b
12	0.58d	0.43c	0.21b
16	0.66de	0.48cd	0.41c
20	0.73e	0.71e	0.42c
24	1.48g	1.00f	0.57d

Means within a sub-table followed by the same
letter are not significantly different at the 5 per
cent of probability.

TABLE Id

EFFECTS OF K^+ TREATMENTS ON THE AMIDE-N

CONCENTRATION IN TOMATO LEAVES GROWN

ON 0.03N $(NH_4)_2SO_4$ IN SOIL

	KCl Concentration		
Days	0	0.04N	0.08N
	Amide-N concentration of plant leaves (mg/g fresh-weight)		
0	0.04a	0.04a	0.04a
4	0.28b	0.25b	0.26b
8	0.32b	0.36b	0.32b
12	0.74d	0.39b	0.33b
16	1.24de	0.38b	0.38b
20	1.44e	0.56c	0.38b
24	1.54e	0.59c	0.42bc

Means within a sub-table followed by the same letter are not significantly different at the 5 per cent of probability.

TABLE Ie

EFFECTS OF K^+ TREATMENTS ON THE TOTAL-N

CONCENTRATION IN TOMATO LEAVES GROWN

ON $0.03N$ $(NH_4)_2S)_4$ IN SOIL

	KCl Concentration		
Days	0	0.04N	0.03N
	Total-N concentration of tomato leaves (% dry weight)		
0	1.01a	1.01a	1.01a
4	3.93d	3.47cd	2.58b
8	4.47e	3.68cd	3.24c
12	4.74ef	3.96d	3.24c
16	4.99f	4.14de	3.33c
20	5.02f	4.43e	3.84d
24	5.43fg	4.53ef	4.04d

Means within a sub-table followed by the same letter are not significantly different at the 5 per cent of probability.

TABLE If

EFFECTS OF K^+ TREATMENTS ON THE K^+

CONCENTRATION OF TOMATO LEAVES

GROWN ON 0.08N $(NH_4)_2SO_4$

IN SOIL

| Days | KCl Concentration | | |
| | 0 | 0.04N | 0.08N |
	K^+ concentration of tomato leaves (% dry weight)		
0	3.60c	3.60c	3.60c
4	2.10b	3.80c	4.50cd
8	2.10b	4.10cd	4.70d
12	1.70ab	4.20cd	5.00d
16	1.40ab	4.40cd	5.00d
20	1.40ab	4.70d	5.30e
24	1.10a	4.80d	6.90f

Means within a sub-table followed by the same letter are not significantly different at the 5 per cent of probability.

TABLE Ig

EFFECTS OF K^+ TREATMENTS ON THE SOIL pH

SUPPLIED WITH 0.08N $(NH_4)_2SO_4$

DAYS	KCl Concentration		
	0	0.04N	0.08N
0	5.30bc	5.30bc	5.30bc
4	4.90a	5.00ab	5.10b
8	5.40cd	5.50cd	5.50cd
12	5.50cd	5.60d	5.50cd
16	5.10b	5.00ab	5.00ab
20	5.60d	5.70d	5.60d
24	5.70d	5.70d	5.70d

Means within a sub-table followed by the same letter are not sifnificantly different at the 5 per cent level of probability.

Experiment II. The Effects of Equinormal
Concentrations of NH_4^+ and K^+ at
Different Sampling Dates on the
Ammonium Toxicity of Tomatoes

The results of a greenhouse soil experiment with tomatoes grown at

four equinormal concentrations of NH_4^+ and K^+ is shown in Tables IIa - IIf.

Stem Lesions

The occurrence of stem lesions was prevented at all four levels of

equinormal concentrations of $(NH_4)_2SO_4$ and KCl (0.01N, 0.02N, 0.04N and

0.08N) (Table IIa). In the absence of KCl, the severity of stem lesions,

in twenty-one days was moderate at 0.01N and 0.02N $(NH_4)_2SO_4$, but very

severe lesion conditions were manifested at 0.04N and 0.08N $(NH_4)_2SO_4$.

Without supplemental K^+, the average occurrence of lesions increased with

time.

Fresh Weight

Equinormal concentrations of NH_4^+ and K^+ (0.01N to 0.04N) increased

the fresh weight of tomato shoots with time (Table IIb). At 0.08N NH_4^+ +

K^+, no significant increases in fresh-weight were observed after seven

days of treatment. The application of 0.01N and 0.02N $(NH_4)_2SO_4$ alone,

respectively, raised the fresh weight, while slight growth occurred at

0.04N $(NH_4)_2SO_4$ and further growth occurred at 0.08N $(NH_4)_2SO_4$. The

application of equinormal concentrations of NH_4^+ + K^+ at 0.01N and 0.02N

resulted in better growth of tomato shoots, when compared with NH_4^+ applied

alone. However, lower equinormal concentrations (0.01N and 0.02N) of NH_4^+

+ K^+ enhanced plant growth more than the higher concentrations at 0.04N

and 0.08N.

Nitrogen Fractions

The application of $(NH_4)_2SO_4$ without KCl at concentrations of

0.01N to 0.08N, progressively increased the NH_4^+ - N, amide-N and

total-N concentrations with time (Table IIc; IId; IIe). The

concentrations of NH_4^+ -N, amide-N and total-N were slight at 0.01N

and 0.02N equinormal concentrations of NH_4^+ and K^+, while concentra-

tions of these soluble nitrogen compounds at 0.04N and 0.08N NH_4^+ and

K^+ showed greater increases with time.

Potassium

The K^+ concentration of tomato leaves was substantially lowered,

when NH_4^+ was supplied alone (Table IIf). Gradual increases in K^+

concentration with time were noticed from 0.01N to 0.08N equinormal

concentrations of NH_4^+ and K^+.

Soil pH

The soil pH of samples treated with 0.01N $(NH_4)_2SO_4$ without KCl,

decreased significantly with time. The soil pH of the samples supplied

with 0.02N, 0.04N and 0.08N $(NH_4)_2SO_4$ remained generally constant from

0-21 days. Soil samples supplied with 0.01N equinormal concentration of

NH_4^++K^+ were not statistically different from those supplied with 0.01N

$(NH_4)_2SO_4$ in the absence of K^+. Similar trends were observed with the

equinormal concentrations of 0.02N, 0.04N and 0.08N $(NH_4)_2SO_4$ + KCl when

compared with 0.02N, 0.04N and 0.08N $(NH_4)_2SO_4$ respectively.

TABLE IIa

EFFECTS OF EQUINORMAL CONCENTRATIONS OF AMMONIUM AND POTASSIUM AT DIFFERENT SAMPLING DATES

ON AMMONIUM TOXICITY AS MEASURED BY STEM LESION RATING IN TOMATOES IN SOIL CULTURE*

DAYS	$0.01N$ $(NH_4)_2SO_4$	$0.01N$ $(NH_4)_2SO_4$ + $0.01N$ KCl	$0.02N$ $(NH_4)_2SO_4$	$0.02N$ $(NH_4)_2SO_4$ + $0.02N$ KCl	$0.04N$ $(NH_4)_2SO_4$	$0.04N$ $(NH_4)_2SO_4$ + $0.04N$ KCl	$0.08N$ $(NH_4)_2SO_4$	$0.08N$ $(NH_4)_2SO_4$ + $0.08N$ KCl
0	0	0a	0a	0a	0a	0a	0a	0a
7	1.00b	0a	1.00b	0a	2.50d	0a	3.00e	0a
14	1.50bc	0a	1.75c	0a	2.75de	0a	3.00e	0a
21	1.75c	0a	2.75de	0a	3.00e	0a	3.00e	0a

* Stem lesion rating (0; none - 3; severe)

Means within a sub-table followed by the same letter are not significantly different at the 5 per cent level of probability.

TABLE IIb

EFFECTS OF EQUINORMAL CONCENTRATIONS OF AMMONIUM AND POTASSIUM AT DIFFERENT SAMPLING DATES

ON GROWTH, AS MEASURED BY THE FRESH WEIGHT OF TOMATO SHOOTS IN GRAMS, IN SOIL CULTURE

DAYS	$0.01N$ $(NH_4)_2SO_4$	$0.01N$ $(NH_4)_2SO_4$ $+ 0.01N$ KCl	$0.02N$ $NH_4)_2SO_4$	$0.02N$ $(NH_4)_2SO_4$ $+ 0.02N$ KCl	$0.04N$ $(NH_4)_2SO_4$	$0.04N$ $(NH_4)_2SO_4$ $+ 0.04N$ KCl	$0.08N$ $(NH_4)_2SO_4$	$0.08N$ $(NH_4)_2SO_4$ $+ 0.08N$ KCl
0	28.50a	28.50a	28.50a	28.50a	28.50a	28.50a	28.50a	28.50a
7	64.50bc	62.25bc	69.50b	63.75bc	45.20b	62.75bc	37.00a	54.00b
14	131.50d	126.50d	91.75c	106.25c	45.70b	98.00c	40.54b	62.25bc
21	148.50de	155.75e	126.25d	149.25de	45.45b	131.50d	33.61a	71.00b

Means within a sub-table followed by the same letter are not significantly different at the 5 per cent level of probability.

TABLE IIc

EFFECTS OF EQUINORMAL CONCENTRATIONS OF AMMONIUM AND POTASSIUM AT DIFFERENT SAMPLING DATES ON THE AMMONIUM-NITROGEN CONCENTRATION (mg/g FRESH WEIGHT) OF TOMATO LEAVES GROWN IN SOIL CULTURE

DAYS	$0.01N$ $(NH_4)_2SO_4$	$0.01N$ $(NH_4)_2SO_4$ $+ 0.01N$ KCl	$0.02N$ $(NH_4)_2SO_4$	$0.02N$ $(NH_4)_2SO_4$ $+ 0.02N$ KCl	$0.04N$ $(NH_4)_2SO_4$	$0.04N$ $(NH_4)_2SO_4$ $+ 0.04N$ KCl	$0.08N$ $(NH_4)_2SO_4$	$0.08N$ $(NH_4)_2SO_4$ $+ 0.08N$ KCl
0	0.01a	0.01a	0.01a	0.01a	0.01a	0.01a	0.01a	0.01a
7	0.12c	0.03ab	0.24e	0.12c	0.39f	0.22d	0.45g	0.24e
14	0.14c	0.05b	0.39f	0.18ed	0.43g	0.22d	0.67h	0.44g
21	0.22d	0.06b	0.72h	0.21d	0.84i	0.43g	0.90i	0.70h

Means within a sub-table followed by the same letter are not significantly different at the 5 per cent level of probability.

TABLE IId

EFFECTS OF EQUINORMAL CONCENTRATIONS OF AMMONIUM AND POTASSIUM AT DIFFERENT SAMPLING DATES

ON THE AMIDE-NITROGEN CONCENTRATION (mg/g FRESH WEIGHT) OF TOMATO LEAVES

GROWN IN SOIL CULTURE

DAYS	$0.01N$ $(NH_4)_2SO_4$	$0.01N$ $(NH_4)_2SO_4$ $+ 0.01N$ KCl	$0.02N$ $(NH_4)_2SO_4$	$0.02N$ $(NH_4)_2SO_4$ $+ 0.02N$ KCl	$0.04N$ $(NH_4)_2SO_4$	$0.04N$ $(NH_4)_2SO_4$ $+ 0.04N$ KCl	$0.08N$ $(NH_4)_2SO_4$	$0.08N$ $(NH_4)_2SO_4$ $+ 0.08N$ KCl
0	0.04a	0.04a	0.04a	0.04a	0.04a	0.04a	0.04a	0.04a
7	0.21e	0.04a	0.12d	0.02d	0.39g	0.10c	0.32f	0.09c
14	0.21e	0.08b	0.29f	0.13d	0.42h	0.22e	1.21j	0.14d
21	0.22e	0.13d	0.44h	0.15d	0.50i	0.31f	1.43k	0.33f

Means within a sub-table followed by the same letter are not significantly different at the 5 per cent level of probability.

TABLE IIe

EFFECTS OF EQUINORMAL CONCENTRATIONS OF AMMONIUM AND POTASSIUM AT DIFFERENT SAMPLING DATES

ON THE TOTAL-N CONCENTRATION (% DRY WEIGHT) OF TOMATO LEAVES GROWN IN SOIL CULTURE

DAYS	$0.01N$ $(NH_4)_2SO_4$	$0.01N$ $(NH_4)_2SO_4$ $+ 0.01N$ KCl	$0.02N$ $(NH_4)_2SO_4$	$0.02N$ $(NH_4)_2SO_4$ $+ 0.02N$ KCl	$0.04N$ $(NH_4)_2SO_4$	$0.04N$ $(NH_4)_2SO_4$ $+ 0.04N$ KCl	$0.08N$ $(NH_4)_2SO_4$	$0.08N$ $(NH_4)_2SO_4$ $+ 0.08N$ KCl
0	1.33a	1.33a	1.33a	1.33a	1.33a	1.33a	1.33a	1.33a
7	4.24d	3.53bc	5.32f	3.20b	4.85ef	4.81e	5.91g	4.84ef
14	4.80e	3.75c	5.54fg	4.41d	5.80g	5.08ef	5.95gh	5.24f
21	5.07ef	4.35d	5.79g	5.05ef	6.00h	5.26f	6.05h	5.62g

Means within a sub-table followed by the same letter are not significantly different at the 5 per cent level of probability.

TABLE IIf

EFFECTS OF EQUINORMAL CONCENTRATIONS OF AMMONIUM AND POTASSIUM AT DIFFERENT SAMPLING DATES

ON THE K CONCENTRATION (% DRY WEIGHTS) OF TOMATO LEAVES GROWN IN SOIL CULTURE

DAYS	0.01N $(NH_4)_2SO_4$	0.01N $(NH_4)_2SO_4$ + 0.01N KCl	0.02N $(NH_2)_4SO_4$	0.02N $(NH_4)_2SO_4$ + 0.02N KCl	0.04N $(NH_4)_2SO_4$	0.04N $(NH_4)_2SO_4$ + 0.04N KCl	0.08N $(NH_4)_2SO_4$	0.08N $(NH_4)_2SO_4$ + 0.08N KCl
0	2.87c	2.87c	2.87c	2.87c	2.87c	2.87c	2.87c	2.87c
7	2.05b	2.03b	2.34bc	2.78c	2.45bc	3.94d	2.32bc	3.97de
14	1.94b	3.75d	1.97b	3.66d	2.00b	4.06de	1.90b	4.31e
21	1.25a	3.97de	1.19a	3.97de	1.19a	4.13de	1.05a	4.38e

Means within a sub-table followed by the same letter are not significantly different at the 5 per cent level of probability.

TABLE IIg

EFFECTS OF EQUINORMAL CONCENTRATIONS OF AMMONIUM AND

POTASSIUM AT DIFFERENT SAMPLING DATES ON THE SOIL pH

DAYS	$0.01N$ $(NH_4)_2SO_4$	$0.01N$ $(NH_4)_2SO_4$ $+ 0.01N$ KCl	$0.02N$ $(NH_4)_2SO_4$	$0.02N$ $(NH_4)_2SO_4$ $+ 0.02N$ KCl	$0.04N$ $(NH_4)_2SO_4$	$0.04N$ $(NH_4)_2SO_4$ $+ 0.04N$ KCl	$0.08N$ $(NH_4)_2SO_4$	$0.08N$ $(NH_4)_2SO_4$ $+ 0.08N$ KCl
0	5.22d	5.22d	5.22d	5.22d	5.22d	5.22d	5.22d	5.22d
7	4.98c	4.95bc	4.82b	4.90bc	5.20d	5.18d	5.42de	5.50e
14	4.94bc	4.65a	4.93c	4.70ab	5.14cd	5.12cd	5.08cd	5.70e
21	4.72ab	4.58a	5.08cd	4.58a	5.10cd	5.05cd	5.40de	5.62e

Means within a sub-table followed by the same letter are not significantly different at the 5 per cent level of probability.

Experiment III. The Effects of K^+ and $CaCO_3$ on

Ammonium Toxicity Reversal on Tomatoes Grown

on 0.02N $(NH_4)_2SO_4$ in Sand Culture

In the experiment designed to show the effects of K^+ and $CaCO_3$

on the reversal of ammonium toxicity symptoms, in sand culture, tomato

plants were first treated with 0.02N $(NH_4)_2SO_4$, until stem lesions

appeared at the first degree of severity.

Stem Lesions

Although visible signs of stem lesion healing were noticed in

some plants treated with 0.02N KCl or $CaCO_3$, this reversal was not

statistically significant after seven days of treatments (Table IIIa).

However, a remarkable disappearance of stem lesion was noticed, after

fourteen days with 0.02N KCl + $CaCO_3$ treatment. Stem lesions became

more severe with time, in plants receiving the 0.02N $(NH_4)_2SO_4$ treatment

alone.

Fresh Weight

Growth, in terms of fresh weight (Table IIIb) showed significant

increases in the 0.02N KCl, and 0.02N KCl + $CaCO_3$ after fourteen days,

and $CaCO_3$ treatment, in seven days, while 0.02N $(NH_4)_2SO_4$ + 0.02N KCl

was not significantly increased until twenty-one days of treatment. No

improvement in growth was observed in plants subjected to 0.02N $(NH_4)_2SO_4$

treatment alone, after seven days.

Nitrogen Fractions

The application of 0.02N $(NH_4)_2SO_4$ in the absence of K^+ increased

the NH_4^+-N, amide-N and total-N concentrations with time (Tables IIIc;

IIId; IIIe). The replacement of 0.02N $(NH_4)_2SO_4$ with 0.02N KCl, almost

completely eliminated the NH_4^+-N and amide-N in seven days (Tables IIIc; IIId), while the total-N concentration (Table IIIe), gradually decreased with time over a period of twenty-one days. A combination of 0.02N KCl + $CaCO_3$ (previously added to the sand culture) gave a similar trend as 0.02N KCl alone. Treatment with $CaCO_3$ alone reduced the NH_4^+-N concentration sharply in seven days (Table IIIc), while total-N concentration was gradually decreased with time (Table IIIe). The amide-N concentration (Table IIId) decreased rapidly in seven days, but rose slightly in fourteen days and twenty-one days. When 0.02N KCl + 0.02N $(NH_4)_2SO_4$ treatment was supplied, there was a decrease in NH_4^+-N in seven and fourteen days, with a rapid increase in twenty-one days (Table IIIc).

Treatment with 0.02N KCl or 0.02N KCl + $CaCO_3$ showed no significant difference between the two treatments in the concentration of amide-N (Table IIId), but the 0.02N KCl + $CaCO_3$ treatment appeared to have a lower concentration of NH_4^+-N (Table IIIe) in twenty-one days. Total-N concentration was reduced more by 0.02N KCl than by the 0.02N KCl + $CaCO_3$ treatment (Table IIIe). Plants treated with 0.02N KCl generally contained lower concentrations of NH_4^+-N, amide-N and total-N, than those of the 0.02N KCl + 0.02N $(NH_4)_2SO_4$ treatment (Tables IIIc; IIId; IIIe).

Potassium

The percentage concentration of K^+ found in plants treated with 0.02N $(NH_4)_2SO_4$ decreased significantly with time, while the K^+ content of plants subjected to 0.02N KCl, 0.02N KCl + $CaCO_3$ and 0.02N $(NH_4)_2SO_4$ + 0.02N KCl treatments respectively, increased considerably (Table IIIf). However, in the $CaCO_3$ treatment, a sharp drop in K^+ content was observed after fourteen days. There was a higher K^+ concentration in plants with

0.02N KCl + CaCO$_3$ at twenty-one days, than 0.02N KCl treatment.

TABLE IIIa

EFFECTS OF DIFFERENT CONCENTRATIONS OF POTASSIUM AND CALCIUM CARBONATE ON

AMMONIUM TOXICITY REVERSAL AS MEASURED BY STEM LESION RATINGS

AT $0.02N$ $(NH_4)_2SO_4$

DAYS	$0.02N$ $(NH_4)_2SO_4$	$0.02N$ KCl	$0.02N$ KCl + $CaCO_3$	$CaCO_3$	$0.02N$ $(NH_4)_2SO_4$ + $0.02N$ KCl
0	1.00b	1.00b	1.00b	1.00b	1.00b
7	1.25bc	0.50ab	0.38ab	0.50ab	0.62ab
14	1.50c	0.25ab	0.25ab	0.25ab	0.75b
21	1.50c	0.25ab	0.12a	0.25ab	1.12bc

Means within a sub-table followed by the same letter are not
significantly different at the 5 per cent level of probability.

TABLE IIIb

EFFECTS OF DIFFERENT CONCENTRATIONS OF POTASSIUM AND CALCIUM CARBONATE ON

GROWTH, AS MEASURED BY FRESH WEIGHT OF TOMATO SHOOTS GROWN IN SAND

CULTURE AT 0.02N $(NH_4)_2SO_4$

DAYS	0.02N $(NH_4)_2SO_4$	0.02N KCl	0.02N KCl + $CaCO_3$	$CaCO_3$	0.02N $(NH_4)_2SO_4$ + 0.02N KCl
0	49.50a	49.50a	49.50a	49.50a	49.50a
7	62.75b	52.75ab	55.50ab	79.25c	54.75ab
14	53.00ab	74.25bc	74.75bc	72.25bc	59.50ab
21	51.25ab	83.00c	89.75c	66.00b	67.75bc

Means within a sub-table followed by the same letter are not significantly different at the 5 per cent level of probability

TABLE IIIc

EFFECTS OF DIFFERENT CONCENTRATIONS OF POTASSIUM AND CALCIUM CARBONATE ON

THE AMMONIUM - NITROGEN CONCENTRATION (mg/g FRESH WEIGHT) OF TOMATO

LEAVES GROWN IN SAND CULTURE AT 0.02N $(NH_4)_2SO_4$

DAYS	0.02N $(NH_4)_2SO_4$	0.02N KCl	0.02N KCl + $CaCO_3$	$CaCO_3$	0.02N $(NH_4)_2SO_4$ + 0.02N KCl
0	0.18c	0.18c	0.18c	0.18c	0.18e
7	0.22ef	0.03ab	0.04b	0.05c	0.13d
14	0.27f	0.03ab	0.03ab	0.04b	0.15d
21	0.32g	0.04b	0.02a	0.02a	0.22ef

Means within a sub-table followed by the same letter are not significantly different at the 5 per cent level of probability.

TABLE IIId

EFFECTS OF DIFFERENT CONCENTRATIONS OF POTASSIUM AND CALCIUM CARBONATE ON

THE AMIDE-NITROGEN CONCENTRATION (mg/g FRESH WEIGHT) OF TOMATO LEAVES

GROWN IN SAND CULTURE AT 0.02N $(NH_4)_2SO_4$

DAYS	0.02N $(NH_4)_2SO_4$	0.02N KCl	0.02N KCl + $CaCO_3$	$CaCO_3$	0.02N $(NH_4)_2SO_4$ + 0.02N KCl
0	0.10c	0.10c	0.10c	0.10c	0.10c
7	0.12d	0.04a	0.04a	0.04a	0.10c
14	0.12d	0.04a	0.04a	0.07b	0.13d
21	0.13d	0.04a	0.03a	0.06b	0.14d

Means within a sub-table followed by the same letter are not significantly different at the 5 per cent level of probability.

TABLE IIIe

EFFECTS OF DIFFERENT CONCENTRATIONS OF POTASSIUM AND CALCIUM CARBONATE ON

THE TOTAL-NITROGEN CONCENTRATION (% DRY WEIGHT) OF TOMATO LEAVES GROWN

IN SAND CULTURE AT 0.02N $(NH_4)_2SO_4$

DAYS	0.02N $(NH_4)_2SO_4$	0.02N KCl	0.02N KCl + $CaCO_3$	$CaCO_3$	0.02N $(NH_4)_2SO_4$ + 0.02N KCl
0	3.21de	3.21de	3.21de	3.21de	3.21de
7	3.76f	2.82c	3.05d	3.27de	3.45e
14	3.80f	2.48bd	2.63c	2.47bc	3.82g
21	4.31g	1.92a	2.38b	2.47bc	4.10fg

Means within a sub-table followed by the same letter are not significantly different at the 5 per cent level of probability.

TABLE IIIf

EFFECTS OF DIFFERENT CONCENTRATIONS OF POTASSIUM AND CALCIUM CARBONATE ON

THE POTASSIUM CONCENTRATION (% DRY WEIGHT) OF TOMATO LEAVES GROWN IN

SAND CULTURE AT 0.02N $(NH_4)_2SO_4$

DAYS	0.02N $(NH_4)_2SO_4$	0.02N KCl	0.02N KCl + $CaCO_3$	$CaCO_3$	0.02N $(NH_4)_2SO_4$ + 0.02N KCl
0	2.25b	2.25b	2.25b	2.25b	2.25b
7	3.72d	4.00de	4.44e	3.00c	3.72d
14	2.41b	4.46e	4.56e	2.11b	3.81d
21	2.19b	4.66e	4.94f	1.44a	4.49e

Means within a sub-table followed by the same letter are not significantly different at the 5 per cent level of probability.

Experiment IV. The Effects of K^+ at Different

Stem Lesion Ratings and Sampling Dates, on

the Reversal of Ammonium Toxicity of

Tomatoes Grown on 0.04N $(NH_4)_2SO_4$

in Soil Culture

A second experiment on the reversal of ammonium toxicity by K^+

was carried out in soil culture. A 0.04N $(NH_4)_2SO_4$ solution was

supplied at 250 ml per plant daily until lesions were formed at 1 (after

three days), 2 (after six days), and 3 (after eight days) degree-ratings.

The results are reported in Tables IVa - IVe.

Stem Lesions

Ammonium toxicity reversal, as measured by the disappearance,

or healing of stem lesions was evident at ratings 1 and 2, fourteen

days after the initiation of treatment with 0.04N KCl alone (Table IVa).

No significant lesion disappearance was noticed at lesion rating 3 with

0.04N KCl treatment. Treatment with 0.04N KCl + 0.04N $(NH_4)_2SO_4$ did not

bring about a reversal of lesions at any level of lesion formation.

The severity of stem lesions in all cases increased with time, with

0.04N $(NH_4)_2SO_4$ application.

Fresh Weight

The fresh weight (Table IVb) of tomato shoots supplied with

0.04N KCl at degrees 1, 2 and 3 lesion ratings indicated substantial

gains seven days, after the initiation of treatments and these

increases continued until fourteen days. When stem lesions were

slight, or moderate, plant growth showed substantial improvement with

time, with the application of 0.04N KCl + 0.04N $(NH_4)_2SO_4$. Under severe

lesion conditions, with the same treatment, significant increases in fresh weight of the shoots were observed after only seven days. Plants supplied with deionized water showed smaller gains in fresh weight with time, at the various degrees of lesion severity than those receiving 0.04N KCl. Continuous application of 0.04N $(NH_4)_2SO_4$ with time (Table IVb), resulted in continuous plant growth at lesion ratings 1 and 2, but caused a decrease with time at the 3 lesion rating.

Nitrogen Fractions

At each degree of lesion severity, 0.04N KCl significantly reduced NH_4^+-N (Table IVc) and amide-N (Table IVd) in seven days after treatment; the total-N concentration steadily decreased over the period of fourteen days (Table IVe). The application of 0.04N $(NH_4)_2SO_4$ + 0.04N KCl at 1, 2 and 3 degrees of lesion severity had no significant effects on NH_4^+-N (Table IVc), but resulted in a reduction of amide-N (Table IVd) and total-N (Table IVe) concentrations in the tomato leaves with time. The reversal of NH_4^+-N (Table IVc), amide-N (Table IVd) and total-N (Table IVe) concentrations with time, with the application of deionized water was as effective as KCl at the lowest lesion rating, but its effect on the amide-N (Table IVd) was less pronounced. At the 2 and 3 levels of lesions, deionized water was generally less effective than KCl in reversing NH_4^+-N, amide-N and total-N concentrations, than it was at the first lesion rating.

Potassium

The K^+ concentrations were significantly increased in all degrees of lesion severity with the 0.04N KCl treatment with time (Table IVf). The concentration of K^+ found in plants treated with 0.04N

$(NH_4)_2SO_4$ + 0.04N KCl (Table IVf) increased with time at the moderate

and severe lesion ratings, but increased significantly only during the

first seven days at the first lesion rating. The K^+ concentrations

in the plants treated with 0.04N KCl and 0.04N $(NH_4)_2SO_4$ + 0.04N KCl

(Table IVf) showed no significant difference between each other at 1

lesion rating. However, higher K^+ concentration was found in the 0.04N

KCl treatment, after seven days of treatment at 2 and 3 lesion ratings,

than the 0.04N $(NH_4)_2SO_4$ + 0.04N KCl treatment.

TABLE IVa

EFFECTS OF POTASSIUM AT DIFFERENT LESION RATINGS (1-3)

SAMPLING DATES ON AMMONIUM TOXICITY REVERSAL

MEASURED BY THE DISAPPEARANCE OF <u>STEM LESIONS</u> ON TOMATOES

IN SOIL CULTURE PREVIOUSLY TREATED WITH 0.04N $(NH_4)_2SO_4$

	TREATMENTS			
DAYS	0.04N $(NH_4)_2SO_4$	0.04N KCl	0.04N $(NH_4)_2SO_4$ + 0.04N KCl	Deionized Water
	1^O Lesion (slight)			
0	1.00b	1.00b	1.00b	1.00b
7	1.25b	1.00b	1.00b	1.00b
14	2.50e	0.38a	1.00b	1.25bc
	2^O Lesion (Moderate)			
0	2.00d	2.00d	2.00d	2.00d
7	2.50e	2.00d	2.00d	2.25e
14	3.00f	1.50c	2.00d	2.75ef
	3° Lesion (Severe)			
0	3.00f	3.00f	3.00f	3.00f
7	3.00f	3.00f	3.00f	3.00f
14	3.00f	2.75ef	3.00f	3.00f

Means within the sub-table followed by the same letter are
not significantly different at the 5 per cent level of probability.

TABLE IVb

EFFECTS OF POTASSIUM AT DIFFERENT LESION RATINGS (1-3)

AND SAMPLING DATES ON GROWTH, AS MEASURED BY FRESH WEIGHT

OF TOMATO SHOOTS (gms) PREVIOUSLY TREATED WITH

$0.04N$ $(NH_4)_2SO_4$ IN SOIL CULTURE

	TREATMENTS			
DAYS	$0.04N$ $(NH_4)_2SO_4$	$0.04N$ KCl	$0.04N$ $(NH_4)_2SO_4$ + $0.04N$ KCl	Deionized Water
			1^O Lesion (Slight)	
0	66.50ab	66.50ab	66.50ab	66.50ab
7	99.75bc	130.25cd	116.75cd	96.50bc
14	71.75b	151.25d	195.75e	142.25cd
			2^O Lesion (Moderate)	
0	62.25ab	62.25ab	62.25ab	62.25ab
7	93.00bc	122.50cd	113.75c	95.00bc
14	41.25ab	160.00d	178.75de	143.75dc
			3° Lesion (Severe)	
0	60.75ab	60.75ab	60.75ab	60.75ab
7	89.64bc	117.00cd	121.00cd	93.00bc
14	31.50a	138.00cd	137.00cd	123.73cd

Means within the sub-table followed by the same letter are
not significantly different at the 5 per cent level of probability.

TABLE IVc

EFFECTS OF POTASSIUM AT DIFFERENT LESION RATINGS (1-3)

AND SAMPLING DATES ON THE <u>AMMONIUM-NITROGEN</u> (mg/g FRESH WEIGHT)

CONCENTRATION IN THE LEAVES OF TOMATO PLANTS PREVIOUSLY TREATED

WITH 0.04N $(NH_4)_2SO_4$ IN SOIL CULTURE

	TREATMENTS			
DAYS	0.04N $(NH_4)_2SO_4$	0.04N KCl	0.04N $(NH_4)_2SO_4$ + 0.04N KCl	Deionized Water
			1^{O} Lesion (Slight)	
0	0.31bc	0.31bc	0.31bc	0.31bc
7	0.53d	0.05a	0.18b	0.07a
14	0.76e	0.04a	0.16ab	0.03a
			2^{O} Lesion (Moderate)	
0	0.38cd	0.38cd	0.38cd	0.38cd
7	0.44cd	0.05a	0.36cd	0.18b
14	1.17f	0.04a	0.21bc	0.07a
			3° Lesion (Severe)	
0	0.46cd	0.46cd	0.46cd	0.46cd
7	0.81e	0.05a	0.33c	0.21bc
14	1.20f	0.05a	0.35cd	0.21bc

Means within the sub-table followed by the same letter are not significantly different at the 5 per cent level of probability.

TABLE IVd

EFFECTS OF POTASSIUM AT DIFFERENT LESION RATINGS (1-3)

AND SAMPLING DATES ON THE <u>AMIDE-NITROGEN</u> (mg/g FRESH WEIGHT)

CONCENTRATION IN THE LEAVES OF TOMATO PLANTS PREVIOUSLY TREATED

WITH 0.04N $(NH_4)_2SO_4$ IN SOIL CULTURE

DAYS	0.04N $(NH_4)_2SO_4$	0.04N KCl	0.04N $(NH_4)_2SO_4$ + 0.04N KCl	Deionized Water
		TREATMENT		
		$1°$ Lesion (Slight)		
0	0.32b	0.32b	0.32b	0.32b
7	0.33b	0.09a	0.17a	0.19a
14	0.48b	0.05a	0.16a	0.13a
		$2°$ Lesion (Moderate)		
0	0.44b	0.44b	0.44b	0.44b
7	0.65b	0.11a	0.31b	0.28a
14	2.34c	0.09a	0.19a	0.16a
		$3°$ Lesion (Severe)		
0	0.52b	0.52b	0.52b	0.52b
7	0.85b	0.11a	0.24a	0.26a
14	3.63d	0.11a	0.38a	0.26a

Means within the sub-table followed by the same letter are not significantly different at the 5 per cent level of probability.

TABLE IVe

EFFECTS OF POTASSIUM AT DIFFERENT LESION RATINGS (1-3)

AND SAMPLING DATES ON THE TOTAL NITROGEN CONCENTRATION

(% DRY WEIGHT) IN THE LEAVES OF TOMATO PLANTS PREVIOUSLY

TREATED WITH 0.04N $(NH_4)_2SO_4$ IN SOIL CULTURE

	TREATMENT			
DAYS	0.04N $(NH_4)_2SO_4$	0.04N KCl	0.04N $(NH_4)_2SO_4$ + 0.04N KCl	Deionized Water
			1° Lesion (Slight)	
0	5.63d	5.63d	5.63d	5.63d
7	6.05de	3.91bc	5.08cd	4.60c
14	6.34e	2.15a	4.59c	3.08d
			2° Lesion (Moderate)	
0	5.88de	5.88de	5.88de	5.88de
7	6.82e	4.44c	5.68d	5.54d
14	6.83e	2.75ab	4.83c	3.86bc
			3° Lesion (Severe)	
0	6.00de	6.00de	6.00de	6.00de
7	6.24de	4.01bc	5.72d	5.68d
14	7.22e	3.50bc	5.74d	5.16cd

Means within the sub-table followed by the same letter are not significantly different at the 5 per cent level of probability.

TABLE IVf

EFFECTS OF POTASSIUM AT DIFFERENT LESION RATINGS (1-3)

AND SAMPLING DATES ON THE POTASSIUM CONCENTRATION

(% DRY WEIGHT) IN THE LEAVES OF TOMATO PLANTS PREVIOUSLY

TREATED WITH 0.04N $(NH_4)_2SO_4$ IN SOIL CULTURE

DAYS	TREATMENT			
	0.04N $(NH_4)_2SO_4$	0.04N KCl	0.04N $(NH_4)_2SO_4$ + 0.04N KCl	Deionized Water
			1° Lesion (Slight)	
0	3.34de	3.34de	3.34de	3.34de
7	3.12de	4.06f	4.22fg	2.34c
14	2.37c	5.19gh	5.06g	1.88b
			2° Lesion (Moderate)	
0	2.97d	2.97d	2.97d	2.97d
7	2.06bc	4.91g	3.72ef	2.41c
14	2.00bc	6.22i	4.99g	2.00bc
			3° Lesion (Severe)	
0	2.19bc	2.19bc	2.19bc	2.19bc
7	2.16bc	4.78g	3.56e	1.82b
14	2.13bc	6.44i	5.53h	1.60a

Means within the sub-table followed by the same letter are not significantly different at the 5 per cent level of probability.

DISCUSSION

The data presented in Tables I to IV show that excessive application of NH_4^+, as a nitrogen source to tomato plants (Heinz 1350) could cause ammonium toxicity. This is in agreement with the findings from several experiments (9, 13, 44). Continuous NH_4^+ supply, in the absence of K^+ could hinder plant growth at 0.04N and 0.08N (Tables Ib, IIb), induce tomato stem lesions at 0.01N, 0.02N, 0.04N and 0.08N (Tables Ia, IIa, IIIa, and IVa), and caused a general increase in the concentrations of NH_4^+-N, amide-N and total-N (Tables I - IV) with time.

Lower concentrations of $(NH_4)_2SO_4$ at 0.01N and 0.02N (Table IIb) had a less deleterious effect on growth and gave lower internal concentrations of the soluble nitrogenous compounds, than the higher concentrations at 0.04N and 0.08N (Tables IIc, IId, IIe). This was probably due to the less toxic effects of NH_4^+ ions at 0.01N and 0.02N, than at 0.04N and 0.08N.

Barker _et_ _al._ (10) have pointed out the injurious effects of NH_4^+ toxicity on the epidermal and cortical cells of the affected stems. It seems possible that the external manifestation of excess NH_4^+, in the appearance of stem lesions may be due to the collapse and death of these cells.

In healthy plants, NH_4^+ supplied at low concentrations and in limited quantity is generally incorporated into non-toxic organic compounds (75). Using ^{15}N labelling, Barker _et_ _al._ (14) found that the major portion of the ammonium and free amino-acids in NH_4^+ toxic plants were of endogenous origin. Hence, he suggested that protein degradation

might have occurred. The high concentrations of total-N observed as a result of $(NH_4)_2SO_4$ supply (Tables Ie, IIe, IIIe, IVe), when K^+ was withheld may be due to protein degradation. Increases in the NH_4-N concentrations in the tomato leaves, may have been caused either by the presence of uncombined NH_4^+ absorbed by the plants, or from protein breakdown.

In plants suffering from ammonium toxicity, the amides and especially asparagine have been detected in considerable amounts in the soluble organic nitrogen concentration (3, 13, 20). Steward and Preston (61) proposed that amides served as nitrogen storage compounds, ready to donate N to synthesis reactions. The high concentration of amide-N under NH_4^+-toxic conditions may be made possible by the fact that the availability of amino-acids and uncombined NH_4^+ accelerated the synthesis of more amides. Or, amide synthesis and the synthesis of amino-acids proceeded at a rate that made some amino-acids unavailable for protein synthesis. Barker (7) seemed to support the latter concept.

The application of 0.04N KCl, along with 0.08N $(NH_4)_2SO_4$ reduced the severity of stem lesions (Table Ia), improved plant growth (Table Ib) and decreased the concentrations of NH_4^+-N (Table Ic), amide-N (Table Id) and total-N (Table Ie) in tomato leaves with time, relative to $(NH_4)_2SO_4$ treatment without K^+. This indicated that K^+ might prevent or reduce NH_4^+ toxicity symptoms. This indication was further confirmed, by the observation that the addition of 0.08N KCl to 0.08N $(NH_4)_2SO_4$, completely prevented stem lesion formation (Table Ia) and further reduced the concentrations of NH_4^+-N (Table Ic), amide-N (Table Id) and total-N (Table Ie). Similar actions of K^+ have been observed (7, 9, 14).

The application of various levels of equinormal concentrations of $NH_4^+ + K^+$ at 0.01N, 0.02N, 0.04N and 0.08N showed that stem lesions were completely prevented (Table IIa), growth, as measured by fresh weight was enhanced (Table IIb), and there was a general reduction in the concentrations of NH_4^+-N (Table IIc), amide-N (Table IId) and total-N (Table IIe), when compared with plants fed with similar concentrations of $(NH_4)_2SO_4$ without K^+ respectively.

In assessing the relative reduction of the soluble nitrogenous compounds, by comparing the concentrations of the various levels of equinormal concentrations of $NH_4^+ + K^+$, with $(NH_4)_2SO_4$ treatments without K^+, it may be concluded that the lower equinormal concentrations of $NH_4^+ + K^+$ at 0.01N and 0.02N brought about a greater reduction of NH_4^+ - N, amide-N and total-N (Tables IIc, IId, IIe), and a better plant growth (Table IIb), than the higher concentrations at 0.04N and 0.08N. Despite the fact that equal concentrations of K^+ and NH_4^+ were present, NH_4^+ ions might have caused toxicity symptoms at a rate too fast for the K^+ ions to neutralize their effects, or the salt concentration may have been too high for growth.

The finding that K^+ imparts a particular configuration to certain enzymes, e.g., pyruvic kinase (28, 31) has given attention to its possible role in maintaining the structure of proteins. NH_4^+ and K^+ ions are similar in ionic radii and may substitute for each other in the isomorphic series (9). These two ions differ in that NH_4^+ will form H-bonds with the oxygen-containing, or other groups of the protein molecule. Hydrogen bonds are very important to the tertiary structure of proteins (9), and if broken, the protein may be subjected to

proteolytic action. Hence, the action of NH_4^+ could possibly be to

cause a disruption of the protein structure to a sufficient extent as

to enhance proteolysis (7, 9). One way to counter NH_4^+ action, would

be to increase the K^+ supply. The function of K^+, therefore, could be

in the maintenance of the protein molecule configuration. This may

explain the growth improvement and the reduction in the concentrations

of NH_4^+-N, amide-N and total-N. Barker and Bradfield (8) further

explained that with higher K^+ nutrition, more of the absorbed NH_4^+ was

being used for the synthesis of insoluble organic N compounds. As a

result, a smaller concentration of N was accumulating in the amides.

From the data on Table III, it is evident that 0.04N KCl, 0.04N

KCl + $CaCO_3$ and $CaCO_3$ respectively, caused reductions in lesion ratings

(Table IIIa), improved plant growth (Table IIIb), and decreased the

concentrations of NH_4^+-N, (Table IIIc), amide-N (Table IIId) and

total-N (Table IIIe) with time, after the tomato plants had been sub-

jected to an initial $(NH_4)_2SO_4$ treatment until lesions were formed at

1 lesion rating. This result suggests that these three treatments were

capable of reversing the ammonium toxicity effects in tomato plants.

Calcium carbonate has been known to facilitate K^+ absorption into

plant roots (30). Barker (7) found more K^+ in the roots of bean plants,

when $CaCO_3$ was added to the nutrient medium, than when it was withheld.

$CaCO_3$ is very effective in neutralizing the acidity caused by the

absorption of NH_4^+ from a nutrient medium, without the formation of

alkaline conditions (7, 30). A result similar to that obtained in

Table III was observed in bean plant, with regards to the $CaCO_3$ effect.

$CaCO_3$ reduced NH_4^+ content of the shoots and prevented protein degradation

(7). Thus, it was postulated that the presence of $CaCO_3$ in the culture medium induced the stabilization of the plant proteins and caused the deceleration of protein degradation, which occurred under conditions of prolonged NH_4^+ nutrition (7). It is also possible that the presence of $CaCO_3$ reduced the transport of NH_4^+ to the tomato leaves and enhanced amide synthesis in the roots as reported by Maynard and Barker (42).

The treatment of plants with 0.04N $(NH_4)_2SO_4$ + 0.04N KCl had a very slight effect in reversing NH_4^+ toxicity, i.e., stem-lesion rating (Table IIIa) and NH_4^+-N (Table IIIc), amide-N (Table IIId), and total-N (Table IIIe) concentration. After seven days of treatment, ammonium toxicity symptoms again became apparent. Two reasons could be advanced for this observation. (a) The application of more NH_4^+ ions, after the initial treatment with $(NH_4)_2SO_4$ to develop lesion 1 degree rating, might have prevented or inhibited K^+ effect, possibly by NH_4^+ ions competing with K^+ ions for absorption by plants or competition within the plants. (b) K^+ might have brought about NH_4^+ toxicity reversal to its fullest capacity, for a short time and the presence of more NH_4^+ ions might have countered the reversal effect of K^+. The first explanation seems justified, because the K^+ concentrations in Table IIIf, at 0.04N $(NH_4)_2SO_4$ + 0.04N KCl treatment, after pretreatment with NH_4^+ were lower than the same concentration of K^+ in 0.04N KCl applied alone. The second explanation, also merits further consideration, judging by the fact that NH_4^+-N (Table IIIc), amide-N (Table IIId) and lesion rating (Table IIIa) were depressed in the first seven days of treatment, and later worsened in fourteen and twenty-one days of treatment. It appears that both processes might take place in the plant.

NH_4^+ toxicity reversal could be effected by KCl treatment at 1,
2 and 3 lesion ratings (Tables IVa - IVe). Deionized H_2O was also
effective in reversing (Tables IVb, IVc, IVd, IVe) NH_4^+ toxicity
symptoms, although H_2O was generally less effective than K^+. In the
presence of deionized H_2O, nitrification might have converted NH_4^+ to
NO_3^-, and since no additional NH_4^+ was supplied, the NH_4^+ level
eventually declined to nothing.

No differences in soil pH were observed when different concentra-
tions of $(NH_4)_2SO_4$ were compared with the different concentrations of
$(NH_4)_2SO_4$ + KCl supplied to the soil (Tables Ig, IIg).

SUMMARY

The results of the investigations conducted in this thesis revealed that prolonged fertilization or absorption of NH_4^+ ions supplied as $(NH_4)_2SO_4$, to tomato plants at 0.01N, 0.02N, 0.04N and 0.08N, in the absence of K^+ caused ammonium toxicity. Ammonium toxicity was manifested in the appearance of stem lesions, which increased in severity with time, upon continuous NH_4^+ application. Other ammonium toxicity symptoms are growth restriction, as measured by the fresh weight of shoot, and high concentrations of NH_4^+-N, amide-N and total-N in the plant tissue.

The presence of K^+, in equinormal concentrations of $NH_4^+ + K^+$ at 0.01N, 0.02N, 0.04N and 0.08N completely prevented the formation of stem lesions, enhanced plant growth and considerably reduced the concentrations of NH_4^+-N, amide-N and total-N in tomato leaves. Increasing concentrations of K^+ supplied to the plants, brought about increases in the concentrations of K found in the leaves.

When ammonium toxicity was induced by pretreating tomato plants with $(NH_4)_2SO_4$, it was observed that either K^+ or $CaCO_3$ or a combination of both K^+ and $CaCO_3$ could cause ammonium toxicity reversal. Deionized H_2O brought about some reversal, but it was not as effective as K^+.

Supplying the soil with $(NH_4)_2SO_4$ alone compared with $(NH_4)_2SO_4 +$ KCl did not effect any significant change in the soil pH.

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