SOME MODIFICATIONS IN THE BEHAVIOR OF <u>LYCOPERSICUM</u> <u>ESCULENTUM</u>, AS A RESULT OF FOLIAR SPRAYS OF MALEIC HYDRAZIDE

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Kalapatti M. Srinivasan

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Charles L. Hamner
Major professor

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LYCOPERSICUM ESCULENTUM, AS A RESULT

OF FOLIAR SPRAYS OF MALEIC HYDRAZIDE

By

KALAPATTI M. SRINIVASAN

AN ABSTRACT

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KALAPATTI M. SRINIVASAN ABSTRACT

Greenhouse experiments were conducted from the fall of 1958 to the spring of 1960, to study some of the physiological responses of tomato following foliar applications of maleic hydrazide (MH). Fruit-set in tomato under high night temperature (70° - 80°F), as influenced by such applicatons was of particular interest. Other responses studied were; general growth responses, accumulation of certain nutrient elements and respiration of roots in MH treated plants.

The following were the noteworthy results recorded:

1. Tomatoes(John Baer) when grown under high night temperatures, produced few flowers, and high flower abscission. Fruit-set was either poor or absent.

2. Under the aforesaid condition, foliar applications of MH (20 p.p.m.) made at a time the first flowers started to open and followed by growth regulator treatments to fully opened flowers (naphthoxyacetic acid at 50 p.p.m. as an aqueous spray) resulted in increasing fruit-set significantly.

3. The indications of the experiments were that difficulty in pollination exists under high night temperature as a secondary factor, and that MH applications can counteract the

detrimental effects of high night temperature.

4. Foliar sprays of MH at 1000 p.p.m. to young tomato seedlings resulted in the inhibition of their vegetative and reproductive growth. The most notable effects were; retardation of stem and root elongation, increase in stem diameter, reduction in number of leaves per plant and decreased length of leaves. Alteration in appearance, color, texture and venation of leaves were also noted.

5. Analysis of MH treated plants (by spectroscopic and chemical methods) indicated that treated plants tend to accumulate lesser amounts of some important nutrients such as nitrogen, potassium, phosphorus, calcium, magnesium, boron, manganese and copper as compared to non-treated plants grown under similar environment and nutritional level.

6. The rate and total accumulation of phosphorus were retarded, when tomatoes were grown in a nutrient culture with varying levels of phosphorus and treated with foliar sprays of MH (1000 p.p.m.). The inhibition induced by MH could not be overcome by increasing the

level of phosphorus in the nutrient culture.

7. Foliar applications of MH (1000 p.p.m.) to young tomato seedlings influenced root elongation, number and location of root hairs and respiration of roots. Root hairs were few and appeared at the very tip of the root. Respiration and root elongation were inhibited.

8. It is believed that MH alters the physiology of young tomato plants and induce inhibition of growth by affecting the root-tips, root hairs, root elongation and respiration of roots.

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INTRODUCTION

Maleic hydrazide is one of the many chemicals whose presence in the plant alters its physiological processes. Applications of maleic hydrazide as a foliar spray to plants are known to result in the retardation of vegetative growth, reduced respiration and accumulation of carbohydrates (21, 44, 45, 46, 53).

When tomatoes are grown under temperatures higher than optimal for their development, vegetative growth becomes dominant, fewer flowers are produced and is followed by heavy abscission of flowers. All these factors result ultimately in poor fruit-set. The entire changes in the growth and development under high night temperature including the poor fruit-set can be explained on the basis of availability of carbohydrates and its subsequent utilization (58, 59, 60, 61, 62). Any attempt to reduce vegetative growth and respiration would seem to favor accumulation of carbohydrates and improve fruit-set under this condition. Hence, in an attempt to improve fruit-set in tomato under high night temperature, foliar applications of maleic hydrazide were undertaken.

In addition to the use of maleic hydrazide for improving fruit-set in tomato under high night temperature, physiological responses of tomato (i.e. growth responses, accumulation of nutrient elements, respiration) as altered by foliar applications of maleic hydrazide were studied.

The objectives of these studies were an attempt to understand some of the physiological responses of the tomato to applications of maleic hydrazide and to gain further knowledge about the manner in which maleic hydrazide could induce inhibition of plant growth.

REVIEW OF LITERATURE

Effect of High Night Temperature on Fruit-Set in Tomato:

Tomato sets fruit abundantly when night temperatures ("nyctotemperatures") are between 15° and 20°C and day temperatures ("phototemperatures") are about 25°C. With higher or lower temperatures, fruiting is significantly reduced or absent (58, 59).

According to Went (62), the factors associated with fruit-set under higher and lower temperatures than optimal are different. Under low night temperature the principle limiting factor appears to be auxin. While under high night temperature the carbohydrate availability seems to be the limiting factor (59, 62). Went (61, 62), has shown in his studies that under high night temperatures the translocation of sugars is poor and there is a predominance of vegetative growth to the detriment of the fruit-set. The poor fruit-set as well as the predominance of vegetative growth under high night temperatures can be easily understood on the basis of competition for available carbohydrates. That deficiency of carbohydrates will result in poor fruit-set in tomato has also been suggested by Kraus and Kraybill (33) and Howlett (29, 30). Murneek (42) has indicated that in tomato under conditions that are not optimal for fruit-set, there exists a negative correlation between vegetative growth and fruiting.

Poor fruit-set can also result from excessive abscission of flowers. Went (62), observed in tomato under both high and low night temperatures abscission of flowers was high. He indicated that abscission of flowers is due to entirely different factors under high and low night temperatures. Flower abscission under high night temperature mainly arises from limitation of carbohydrates while limitation of auxin induces flower abscission under low night temperature (47, 62). Howlett (29), has shown that deficiency of carbohydrates can induce sterility of pollen in tomatoes. Hence, under high night temperatures where there is deficiency of carbohydrates, failure of pollination could also be expected.

Once the fruit has set, its subsequent development is not hampered under high night temperatures (62). On the whole the poor fruit-set in tomato under high night temperature seems to mainly rest in the failure of flowers to develop into fruits. This in turn appears to rest primarily on the availability of carbohydrates. The unfavorable utilization of carbohydrates in the vegetative growth in preference to fruit-set, the production of fewer flowers, tendency for a high flower abscission and the possibility of failure of pollination should all be recognized in considering the fruit-set in tomato under high night temperature.

General Characteristics and Present Uses of Maleic

Hydrazide (MH):

The general biological effect is that application of maleic hydrazide results in plant growth inhibition. Its chemical ingredient is 1, 2-dihydro-3, 6-pyridazinedione. The formulations available for experimental and general uses are:

a. MH-40, a water soluble powder of the sodium salt of MH, with wetting agent and sticker, containing 40% MH acid equivalent.

b. MH-30, a solution of MH, as a diethanolamine salt, containing 30% MH acid equivalent by weight.

MH is used as a herbicide (14), since its applications have been noted to be effective in preventing regrowth of rhizomes (5), flower formation and seed germination (7, 67). MH treated plants show inhibition of growth (12, 40, 53), and this property has been made use of in reducing the frequency of mowing lawns, preventing terminal growth of shade and fruit trees, and for stopping regrowth of tobacco suckers (51, 67). MH applications can also be used to substitute hand pruning and for breaking apical dominance in strawberries and chrysanthemums respectively (2, 28). Since MH treated plants show reduced rates of respiration, it has found applications in preventing storage losses in onions and sugar beets and extending life of cut roses (57, 64, 66). Application of MH to plants results in the accumulation of carbohydrates, retardation of vegetative growth, and has also been used for providing winter hardiness in citrus seedlings (68). MH is used for promotion of abscission of olives (25) and for inducing male sterility in cucurbits (27).

MH applications are noted to induce an inhibiting effect on cell division even in dilute concentrations (23). The inhibibition of cell division in MH treated plants has been found to be largely restricted to the meristematic zones (10). Chromosome breakages following applications of MH are of common occurrence (8). Since the meristems are influenced, it is not surprising to find as a result of treatment with MH, the appearance, growth and development of plants are altered. MH applications also profoundly influence the physiological processes such as respiration, photosynthesis and transpiration (6, 45, 67).

General Growth Responses of Plants, Following Foliar Applications of MH:

Schoene and Hoffman (53) were the first to describe the effects of applications of MH on plant growth. Since their report, this compound has aroused interest in agricultural research. One of the widely reported effects of application of MH on plants is that it retards their growth. Naylor and Davis (44), found that a wide group of plant species show a remarkably uniform effect to applications of MH. By applying MH as a foliar spray from 0.05 to 0.4 percent concentrations, on oat, wheat, redtop grass, corn, peas, peanuts, sunflower, cocklebur, tomato, tobacco and cotton, they concluded that the following were the chief responses observed:

1. Cessation of activity of terminal meristem
2. Cessation of elongation of internodal region
3. Increase in stem diameter

Greulah (18), reported much more marked inhibition of MH treated tomato plants than that observed by Schoene and Hoffman (53). He found that stem diameter of treated plants was inhibited rather than increased. In addition to some of the responses observed by Schoene and Hoffman (53), Greulah (18, 19, 20) noted alteration of leaf morphology, inhibition of leaf growth, delay in flowering and accumulation of anthocyanin pigments in MH treated tomatoes. The loss of sensitivity with increasing age in tomato and other plants in their response to MH has also been reported (13, 19, 44).

Responses of tomato plants to foliar applications of MH have not been consistent. The same author working on one and the same variety of tomato observed at different times some what different responses. Greulach (19) showed that the differences in responses he observed in his experiments as well as by others could be possibly due to the difference in age of the seedlings. It is also possible that these varying effects of MH in inducing responses are due to different degrees of penetration of MH depending upon the conditions under which experiments are carried out. That relative humidity is a factor which will influence rate of absorption of MH by plants has been known (54).

Roots appear to be more sensitive to applications of MH than shoots (4). Both stimulation as well as inhibition of roots have been reported. The concentration of the chemical is the determining factor in inhibition or stimulation of roots (3, 4). In corn, foliar applications of MH at 1 to 10 p.p.m. stimulated root elongation and at 500 p.p.m it inhibited the roots (9).

Following foliar applications of MH it altered the color, texture and development of leaves. The leaves became dark green, leathery and brittle and young leaves failed to expand (4, 18, 20). In certain cases exudates containing mostly sucrose appear as droplets in MH treated plants (13).

Flowering in plants is affected by foliar applications of MH (18, 19, 40, 43, 52). The general tendency of MH is to induce inhibition of flowering. The induction of male sterile flowers ensuing MH applications has also been observed (27). In general MH treatment alters the size, structure, number and time of anthesis of flowers.

Application of MH as a spray to flowering panicles of oat at concentrations ranging from 0.03 to 0.75 percent, has been noted to affect the embryonic development and consequently, the seedlings that arise from such seeds (38).

It can be concluded that applications of MH alters the growth and development of seedlings. These changes resulting in plants by MH treatments are strong indications that the physiology and metabolism of plants are altered. The changes induced in the growth and development of seedlings by MH, are better understood if one reviews the changes induced in the anatomy, physiology and chemical composition of treated plants.

Physiological Changes in Plants Induced by MH Application:

The increase in shoot/root ratio following application of MH in tomato as well as in other plants have been reported (19, 20). This suggests imbalance between top and root growth with the possibility of interference in translocation and distribution of food material.

MH treated plants reveal alteration in their photosynthesis (6), respiration (31), and transpiration (67). When such processes are affected it has a natural consequence on the metabolism of treated plants.

Naylor and Davis (45, 46), found that MH treated excised roots of peas, sunflower, tomato, barley, wheat and oat showed alteration in the respiration. The respiration rates of the tomato, sunflower, oat, wheat and barley were more inhibited than in peas or corn. Henderson and Thomas (26) treated excised stem of pea and sunflower with MH at concentrations from 800 to 1000 p.p.m. and reported that oxygen uptake was decreased in pea stems. Low concentrations of MH will stimulate respiration and higher concentrations will inhibit it (31).

One of the probable methods by which MH induces inhibition of plant growth is due to its effects on plant respiration. When respiration in higher plants is inhibited cessation of growth or undesirable morphological changes may occur (17, 31, 32).

Application of MH increases photosynthetic activity, which is not always accompanied by increase in dry matter (6). The increase in photosynthetic activity observed in plants treated with MH, is attributed to the modification of the physiology of individual cells as a result of treatment (6).

MH treatment of plants may result in reduced rate of transpiration as well as uptake of water (40, 55, 67).

Foliar application of MH to plants have influenced the enzyme systems in them (15, 34). In preparations of artichoke, cauliflower and pea, applications of MH were noted to inhibit dehydrogenase activity, both in the soluble and mitochondrial systems. This indicates that MH can act on the -SH group of enzymes (15).

Leopold and Klein (37) suggested that MH acts as an anti-auxin. They found that growth inhibition produced by low concentrations of MH could be counteracted by addition of auxin and conversely inhibition of growth by high concentrations of auxins relieved by MH. This reversal in action was independent of pH and furthermore no indication could be found that MH acted by chemically combining with the auxin.

On the whole MH applications result in the alteration of physiological activities of the plants. The extent to which they are influenced is dependent on the concentration of the chemical, plant species, and environmental conditions.

Anatomical Changes Induced by MH Applications in Plants:

Foliar applications of MH induce changes in the anatomy of shoots, roots and leaves (16, 23, 24). The nature of changes brought about by MH treatments in them indicates that the inhibition of plant growth following application is due to inhibition of meristematic activity and abnormal enlargement of cells. Collapse of phloem elements, absence of metaxylem and secondary xylems in the bundles, a general disorganized arrangement of cells, disintegration of chloroplasts, abnormal development and degeneration of stomata and absence of guard cells have all been observed in MH treated plants (8, 16, 23, 24). The nature and extent of changes brought about by MH in the anatomy of shoots and roots are influenced by the concentration of the chemical, the treated plant species, and the stage and development at the time of treatment.

Effect of Foliar Applications of MH on Chemical Composition and Mineral Accumulation of Plants:

The effect of foliar applications of MH on chemical composition of plants have been studied to some extent. MH treated plants have been observed to show alteration in carbohydrate, soluble sugars and protein content

(13, 21, 34, 64, 65, 66, 67). The outstanding effect of MH applications is the accumulation of carbohydrates and reduction in proteins.

Uptake and accumulation of nutrient elements ensuing applications of MH have been studied only to a limited extent. Peterson and Naylor (49) found that MH treated tobacco plants had higher calcium and lower phosphorus content. Wildon (63) found that a repeat application of 500 p.p.m. solution of MH to tobacco seedlings retarded accumulation of all major and minor elements in shoots and roots. Bose (4) treated young tomato seedlings with foliar sprays of MH at 10, 50 and 100 p.p.m. solution and observed that uptake of nutrient elements were retarded. Greulach (22) found while application of growth substances could not counteract the inhibition in growth induced by MH in sunflower, repeated foliar applications of complete nutrient sprays helped to relieve the inhibition. MH treated plants often show deficiency symptoms of phosphorus (19, 65) which indicates that phosphorus uptake may be affected.

From the few published reports on accumulation of nutrient elements in MH treated plants it is evident that roots are unable to take up from the media effectively the nutrient elements needed by the plants. Since uptake of nutrient elements are influenced by treatment, it is conceivable that some of the changes in growth responses witnessed in MH treated plants could also be secondary effects not attributable to the chemical alone. Furthermore, applications of MH will influence factors associated with absorption of nutrient elements, particularly permeability of membrane, osmotic pressure and exchange capacity of roots.

MATERIALS AND METHODS

Greenhouse experiments were conducted from the fall of 1958 to the spring of 1960, to study some of the physiological responses of tomato following foliar applications of MH. Among the responses studied, fruit-set in tomato under high night temperature, as influenced by such applications was of particular interest. Other studies were the following:

a. General growth responses resulting from foliar applications of maleic hydrazide.
b. Accumulation of certain nutrient elements of interest in maleic hydrazide treated plants.
c. Rate and total accumulation of phosphorus in maleic hydrazide treated plants grown in a nutrient culture with varying levels of phosphorus.
d. Respiration of roots as influenced by foliar applications of maleic hydrazide.

Cultural Procedure:

The two tomato varieties used in the experiments were John Baer and Michigan Ohio Hybrid. The former was utilized particularly in the experiments related to fruit-set under high night temperature, and in experiments pertaining to growth responses, and accumulation of certain nutrient elements of importance. John Baer was chosen because it can better withstand the high night temperature ranges (70° - $80^{\circ}F$) in the experiments (36). The latter, Michigan Ohio Hybrid, was used in experiments related to rate and total accumulation of phosphorus and respiration of roots following foliar applications of maleic hydrazide; since selection of more uniform seedlings was possible in this variety than in John Baer.

In all the experiments seeds were sown in soil contained in wooden flats which were placed on greenhouse bench. The seedlings were subsequently selected for uniformity and planted to pots of the required size containing either sand or greenhouse soil as desired. The selection for uniformity was based on height and leaf length of seedlings. A further elimination of seedlings that were not uniform was also made before applications of MH. Thus variation due to size and age of seedlings was reduced.

Plants were watered daily with measured quantity of water. The seedlings were given nutrient solutions as needed. Half molar stock solutions of calcium nitrate, magnesium sulfate, and potassium dihydrogen phosphate were first prepared. The final nutrient solution was prepared by utilizing nine milliliters of each of the half molar solutions per liter of water. Each seedling received 250 milliliters of the nutrient solution during its early stage of growth. The amount used was raised to 500 milliliters at a later stage of its development. Seedlings grown in pots filled with fine sand received their nutrient solutions on alternate days, whereas seedlings grown in pots filled with greenhouse soil received the nutrient solution once a week. In the nutrient culture experiment related to rate and total uptake of phosphorus by tomato seedlings treated with MH, when grown under varying levels of phosphorus with all other nutrients at the same level, a different solution and procedure was adopted. This is described in the latter part of 'material and methods' given for individual experiments.

MH was available as a 30 percent diethanolamine salt. From this stock solution, a 1000 p.p.m. solution of MH was prepared in distilled water and was subsequently used for the preparation of other concentrations. All applications of MH were made as foliar sprays until the leaves were completely saturated with the solution. When MH was applied, the soil and the flower clusters, if any, were covered with polyethylene sheets to prevent contact with the chemical sprays.

The growth regulator used in the fruit-set experiment was β naphthoxyacetic acid (BNOA) and was applied as an aqueous spray at 50 p.p.m. solution to only the fully opened flowers.

All the experiments were conducted at temperatures, ranging from 70° - 80°F, utilizing the natural photoperiods available during the seasons in which they were carried out. Conditions related to experiments on fruit-set deserve an additional mention. These experiments were conducted during winter and early spring when it was possible to maintain the high night temperatures required. Special attention was paid to keep the night temperature at 70° - 80°F. The average length of the day, during the period of these experiments, ranged between 9 to 10 hours. The temperature ranges maintained in this experiment, particularly the high night temperature, is high for any variety of tomato (62). Since conditions related to the experiments were not available in the field, experiments had to be confined to the greenhouse.

Sampling Methods and Procedures Used in the Analysis of Plant Materials:

Wherever plant samples were collected for purposes of analysis, the following general procedure was adopted: The plants were removed carefully from the pots in such a manner as to permit maximum possible retention of roots. The the above ground portions and roots were separated. The roots were washed repeatedly with water to remove all the soil particles, and at the same time only minimum loss of roots was allowed. Then the roots were carefully blotted to remove as much of the moisture as possible. The shoots and roots were transferred into paper bags, properly labelled, to permit each treatment as well as roots and shoots in each treatment, being maintained separately. These were then dried in an oven kept at 70°C, for three days. After recording their dry weights, they were ground, and kept in well stoppered bottles. The bottles in turn were maintained in the dessicators until the samples were needed for analysis.

Spectrographic and chemical methods were used to determine the nutrient elements. Nitrogen was estimated by Kjeldahl's method, potassium by flame photometric methods (1), calcium, magnesium, phosphorus, manganese, boron and copper by spectrographic methods, (11). Phosphorus, in one of the experiments (experiment IV) was determined by developing molybdenum blue color on the plant extract obtained by wet ashing with nitric acid and perchloric acid methods as described by Piper (50).

The above procedure is a broad outline of general materials and methods used in these experiments. Additional details for individual experiments, wherever necessary are provided separately.

I. Experiments on fruit-set in tomato grown under high night temperature, 70° - 80°F:

Two experiments were designed during 1958 - 1959, in an effort to determine the effect of foliar applications of MH on fruit-set in tomato grown under high night temperature, $70^{\circ} - 80^{\circ}F$. Seedlings were grown in eight-inch pots filled with greenhouse soil, one seedling per pot.

Each of these experiments included the following four major groups of treatments:

a. Foliar applications of MH at the time the first flower in the first cluster started to open

b. An aqueous spray of BNOA to fully opened flowers

c. Combination of MH and BNOA

d. Control

The control plants indicate the effect of high night temperature on fruit-set as well as provide comparisons for other treatments.

The general design of the experiments provided for replications and randomizations of treatments. Each single plant in a pot was considered as a replicate. Based on the number of flowers taken for each treatment, flower abscission and fruit-set were expressed as a percentage. Whenever comparisons of treatments for evaluating fruit-set was required, a 't' test was run.

The first experiment was conducted between November, 1958, to February, 1959 (winter), and the second experiment was between February to April, 1959 (early spring). The average length of the day, and light intensities in experiment 1, were comparatively less than in experiment 2.

The number of plants and flowers utilized for the treatments in both the experiments are shown in Table 1.

Applications of foliar sprays of MH, in experiment 1, were made on January 7th, 1959, when the first flowers started to open. In experiment 2, similarly applications of MH were conducted on April 3rd, 1959.

II. <u>Experiments related to general growth responses of tomato to foliar applications of MH</u>:

The growth responses of tomato as affected by foliar applications of MH, was determined during summer 1959. On June 20th, 1959, the tomato seedlings growing in eight-inch pots filled with fine sand were separated into four groups. Each pot contained a 47 day old seedling and solutions of MH was applied as a foliar spray at concentrations of 10, 100 and 1000 p.p.m. Non-treated plants served as the control. Each single plant in a pot was considered a replicate and 15 seedlings were alloted for each treatment. The treatments were then randomized on the greenhouse benches.

Following applications, periodic observations were made for the length of the stem, stem diameter, number of leaves, length of the largest leaf, length of flower clusters, and number of flowers and green buds produced in all the treatments. The activity of the terminal meristem of the shoot, color, texture and venation of the leaves were also recorded. For examination of roots some plants were removed from each treatment periodically. The total number of such plants removed were three per treatment.

Table I: Number of Plants and Flowers Utilized in Experiments Related to Fruit-Set in Tomato (John Baer), Under High Night Temperature

Experiment 1:

Treatments*	Number of plants per treatment	Number of flowers per treatment
Group I (MH)	44	156
a. 10 p.p.m.	14	51
b. 20 p.p.m.	14	50
c. 40 p.p.m.	16	55
Group II (BNOA)	10	32
Group III (MH + BNOA)	48	159
a. MH 10 p.p.m. + BNOA	16	53
b. MH 20 p.p.m. + BNOA	16	54
c. MH 40 p.p.m. + BNOA	16	52
Group IV (Control)	16	54

Experiment 2:

Treatments*	Number of plants per treatment	Number of flowers per treatment
Group I (MH)	16	58
Group II (BNOA)	8	28
Group III (MH + BNOA)	16	55
Group IV (Control)	8	32

*Treatments: (MH) as a foliar spray; (BNOA) as an aqueous spray to fully opened flowers: (MH + BNOA) as their combinations. In Experiment 2, MH was used at 20 p.p.m. only.

The experiment was terminated on July 20th, one month after application of MH, when the control flowered. The plants were harvested and six plants from each treatment were removed for subsequent analysis, to determine the amounts of nutrient elements of interest.

III. Experiments related to determinations of nutrient elements of interest in MH treated plants:

Tomato seedlings, six each per treatment, removed from the previous experiment on July 20th, 1959, provided the samples needed for analysis. The methods of collecting samples and procedures of determining the nutrient elements have already been mentioned (p. 17-18). The following nutrient elements were determined: Nitrogen, potassium, phosphorus, calcium, magnesium, boron, manganese, and copper.

The accumulation of each nutrient element in the various treatments was determined by the following formula:

$$\text{Amount of nutrient element per plant} = \frac{\text{Av. dry weight of plant X Av.\% mineral}}{100}$$

IV. Experiment concerning rate and total accumulation of phosphorus in MH treated tomato plants grown in a nutrient culture with varying levels of phosphorus:

In a nutrient culture, by maintaining all other nutrients except phosphorus at the same level, the rate and accumulation of phosphorus in MH treated plants as compared to non-treated plants growing under similar conditions were studied. The levels of phosphorus in the experiments were

16, 32, 64 and 128 p.p.m.

Tomato seedlings were grown in one gallon glazed pots containing the nutrient solutions. Provisions were made for maintaining equal volumes of nutrient solutions in all pots as well as for having regulated air supply. Each pot accomodated four tomato seedlings.

The design of the experiment provided for replications. For each level of phosphorus, six pots were alloted. Out of this, in each level of phosphorus, seedlings in three pots were used for MH treatments. Thus 12 seedlings for each level of phosphorus were treated with MH, and 12 were left non-treated. Each single seedling was considered as a replicate.

On December 6th, 1959, when seedlings were 30 days old, two seedlings were removed from each pot for each level of phosphorus present,at the time of application of MH. On January 3rd, 1960, all seedlings were removed from all the treatments for final determinations of phosphorus.

Besides determining the amounts of phosphorus, observations were made on the general condition and appearance of plants.

The nutrient solutions used in the experiment for providing the desired levels of phosphorus are shown in Table 2.

The preparation of nutrient solutions was a modification of one suggested by Meyer (39).

Nutrient solutions were changed once a week.

Table 2. Proportion of One Molar Salt Solutions Required to Make Up 18 Liters of Final Nutrient Solutions:

Level of Phosphorus	KNO_3	KH_2PO_4	$Ca(NO_3)_2$	$MgSO_4$	KCl	NaH_2PO_4
16 p.p.m.	36 ml.	9 ml.	54 ml.	36 ml.	27 ml.	___ml.
32 p.p.m.	36 "	18 "	54 "	36 "	18 "	___"
64 p.p.m.	36 "	36 "	54 "	36 "	___"	___"
128 p.p.m.	36 "	36 "	54 "	36 "	___"	36 "

To 18 liters of completed solution, 18 ml. of ferric tartarate and 18 ml. of minor element solutions were added.

Preparation of Minor Element Solution:

H_3BO_3	5	grams
$MnCl_2.2H_2O$	3.6	"
$ZnCl_2$	0.2	"
$CuCl_2.2H_2O$	0.1	"
MoO_3	0.15	"

All were dissolved in two liters of distilled water.

V. Experiments related to influence of foliar applications of MH on root hairs and respiration of roots:

The influence of foliar applications of MH on respiration of roots were studied. For this purpose tomato seedlings were grown in four-inch pots filled with fine sand. Solutions of MH was applied as a foliar spray at 1000 p.p.m. when the seedlings were one month old. Each pot contained one seedling. Following application of MH, root tips were removed at needed intervals for determination of rates of respiration. A group of non-treated plants were used as control for comparative measurements.

Oxygen uptake was determined by Warburg Respirometer by using standard manometric techniques (56). An initial trial determination showed that 20 root tips of 1 cm. length each, collected from six plants, per flask was adequate for measuring oxygen uptake. Root tips from MH treated plants could not be used for more than one hour in the determination results. Each treatment was duplicated and the amount of oxygen utilized was recorded in microliters per milligram dry weight of root tips. Root tips for final determinations were collected 192 hours after application of MH.

A group of tomato seedlings grown in sphagnum moss, soaked in nutrient solutions and kept wrapped in polyethylene sheets were used for studying the influence of MH on root hairs.

Out of the 24 seedlings grown in this manner, half of them were treated with solutions of MH, applied as a foliar spray at 1000 p.p.m. The seedlings were one month old at the time of treatment. Ensuing application the nature of root hairs formed was carefully observed periodically.

Since the seedlings were wrapped in polyethylene sheets, it was easy to unwrap the sheets and observe the root hair development without removing and disturbing the seedlings. After an examination they were wrapped up again and this permitted observation on the same seedlings each time.

RESULTS

I. Fruit-set in tomato (John Baer) grown under high night temperature (70° - $80^{\circ}F$) as influenced by foliar applications of maleic hydrazide, growth regulator treatment to fully opened flowers and Their Combinations:

Tomatoes grown under high night temperature produced fewer flowers per cluster. On an average each plant had 3.4 to 3.6 flowers per cluster, (Appendix Table 1). Subsequent to flowering, abscission of flowers was recorded to be high (Tables I, II). All these resulted in poor or no fruit-set (Tables I, II, Figure 1).

Under this condition, foliar applications of maleic hydrazide combined with growth regulator treatment to fully opened flowers improved fruit-set (Tables I, II). The increase in fruit-set noted in this treatment as compared to the control, was significant at the 1% level (Table II A). Neither applications of foliar sprays of maleic hydrazide, nor treatment of fully opened flowers with growth regulator alone, resulted in significantly better fruit-set than the control, (Table II A).

It was observed that whenever applications of maleic hydrazide was combined with growth regulator treatment, besides the terminal flower, other flowers developed into fruits.

<u>Table I</u>: Influence of Foliar Applications of Maleic Hydrazide, Growth Regulator Treatment to Fully Opened Flowers, and Their Combinations, on Flower Abscission and Fruit-Set in Tomato (John Baer), When Grown Under High Night Temperature (70°- 80°F). Experiments Conducted During November, 1958 to February, 1959.

Treatments*		Flower Abscission in percentage	Fruit-Set in percentage
I.	Control	100	0
II.	BNOA	96.87	3.13
III.	MH - 10 p.p.m.	100	0
	MH - 20 p.p.m.	100	0
	MH - 40 p.p.m.	100	0
IV.	MH - 10 p.p.m. + BNOA	94.34	5.66
	MH - 20 p.p.m. + BNOA	90.74	9.26
	MH - 40 p.p.m. + BNOA	96.15	3.85

*<u>Treatment symbols</u>: MH - Maleic Hydrazide

BNOA - β naphthozyacetic acid as an aqueous spray at 50 p.p.m.

MH + BNOA - Combinations

Table II: Influence of Foliar Applications of Maleic Hydrazide, Growth Regulator Treatment to Fully Opened Flowers, and Their Combinations, on Flower Abscission and Fruit-Set in Tomato (John Baer) When Grown Under High Night Temperature (70° - 80°F). Experiments Conducted During February to May, 1959.

Treatments'		Flower Abscission in percentage	Fruit-Set in percentage
I.	Control	90.62	9.38
II.	BNOA	85.71	14.29
III.	MH - 20 p.p.m.	75.69	24.31
IV.	MH - 20 p.p.m. + BNOA	65.82	34.18

Table II A: Comparison of Data Obtained on Fruit-Set (in Table II) For Statistical Significance.

Treatments Compared		't' Distribution
I.	Control vs BNOA	0.59
II.	Control vs MH	1.96
III.	Control vs MH + BNOA	3.30**
IV.	MH + BNOA vs BNOA	2.16*
V.	MH + BNOA vs MH	1.16

**Significant at 1% level
* Significant at 5% level

'Treatment symbols:

MH - Maleic hydrazide; BNOA - β naphthoxyacetic acid;
MH + BNOA - Combinations.

Figure : 1

Fruit-set in tomato (John Baer) grown under high night temperature (70° - 80°F) as influenced by applications of growth regulator to fully opened flowers, and combined treatments of foliar applications of maleic hydrazide and growth regulator.

Upper:

<u>Left to right</u>: Control, growth regulator alone and combination of growth regulator and maleic hydrazide.

(Note the lack of fruits in control, only the terminal flower developing into fruit in growth regulator treatment and in combined treatments of maleic hydrazide and growth regulator, besides the terminal flower other flowers also developing into fruits.)

<u>Lower</u>: A group of fruits obtained by the combined treatments of maleic hydrazide as a foliar spray and growth regulator to fully opened flowers.

In other treatments whenever fruits set, it was always the terminal flower which developed into fruit (Figure 1).

In experiment 2, which was conducted during February to May 1959, better fruit-set was recorded for all the treatments as compared to experiment 1, which was carried out between November 1958 to February 1959. In the former better light intensities as well as longer days existed as compared to the latter.

II. Physiological responses of tomato as influenced by foliar applications of maleic hydrazide:

A. General Growth Responses:

Foliar applications of maleic hydrazide to young tomato plants (John Baer) resulted in the alteration of their growth and development. The growth responses elicited by such applications indicated that treatment with maleic hydrazide sprays will induce inhibition of plant growth. The chief responses observed were:

1. Rate of stem elongation was retarded.
2. Stem diameter was increased.
3. The number of leaves per plant were reduced.
4. The length of the leaf was shortened.
5. The color, texture, and venation of leaves were altered, i.e. the leaves dark green, leathery and brittle and venation less prominent.
6. Root elongation was inhibited and fewer root-hairs developed.

The extent to which changes were brought about by applications of maleic hydrazide in tomato seedlings, were influenced by the concentration of the chemical.

The total amount of growth made by the stem in maleic hydrazide treated plants and the control, from the time of application of the sprays to the end of the experiment is shown in Graph 1. With increasing concentrations of maleic hydrazide, the rate of stem elongation decreased. The control plants had the maximum elongation of stem.

The lowest concentration used (10 p.p.m. solution) had the least effect on the appearance and growth of plants. Plants treated with 10 p.p.m. solutions of maleic hydrazide sprays resembled the control (untreated) in almost every respect. Growth measurements made (Table III) in plants treated with 10 p.p.m. solutions were compared with those of untreated plants, statistically. Except for shoot weights the other growth measurements did not show any significant differences as compared to the control. The reduction in shoot weights was significant at the 1% level.

Plants sprayed with 100 p.p.m. solutions of maleic hydrazide as compared to the control revealed that the differences between them for the following growth measurements (Table III) were significant at the 1% level:

a. Height
b. Stem diameter
c. Number of leaves per plant
d. Dry weights of shoots.

GRAPH. 1

Stem elongation in tomato as influenced by MH.

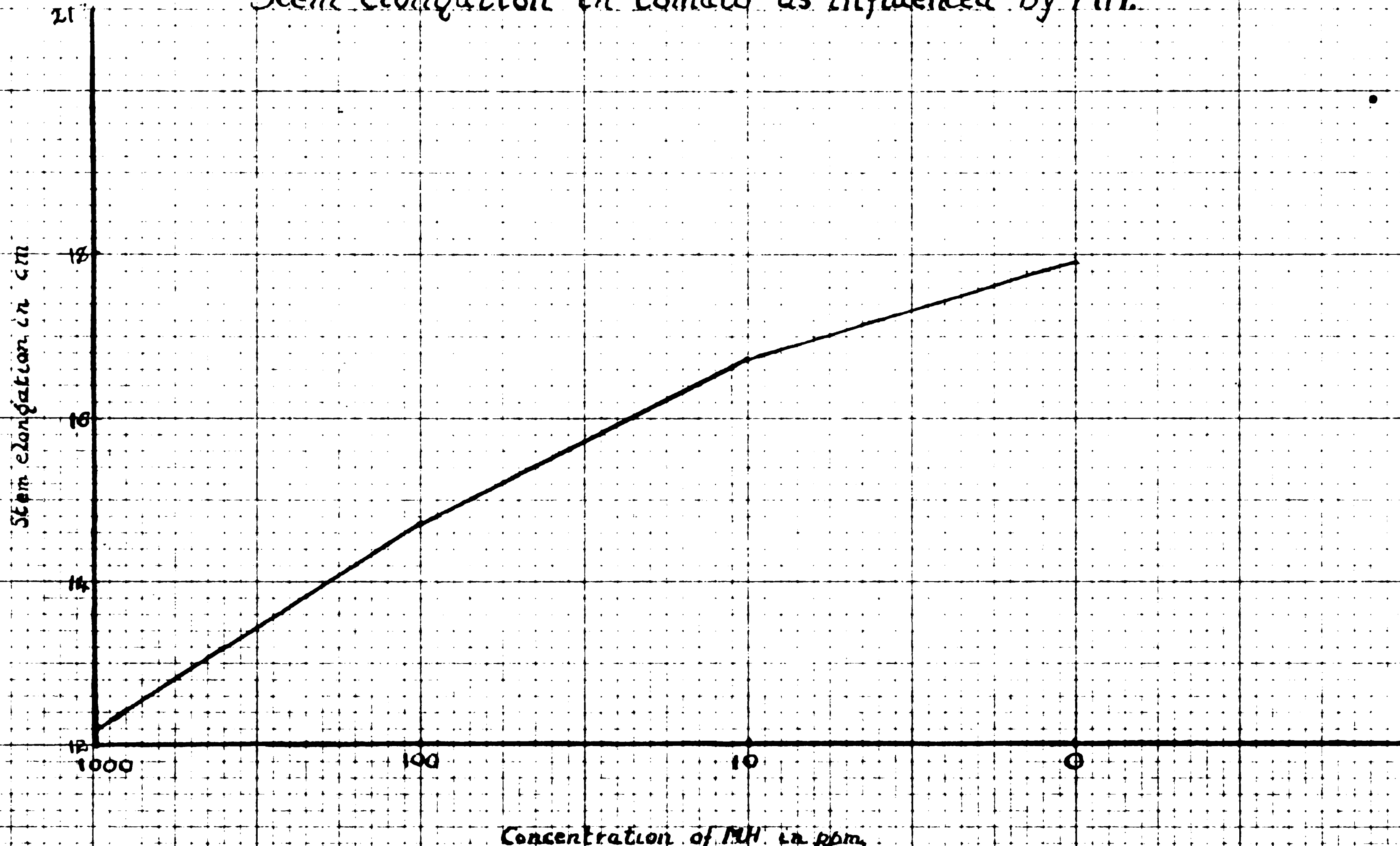

Table III: Growth Measurements of Tomato (John Baer) as Influenced by Varying Concentrations of Maleic Hydrazide, When Applications Were Made as a Foliar Spray to 47 Days Old Seedlings:

Measurements*	Treatments				L.S.D. for treatments	
	Control	10p.p.m.	100p.p.m.	1000p.p.m.	5%	1%
1. Height (in cms)	30.11	28.57	26.85	24.40	1.45	2.00
2. Stem Diameter (in mm)	5.18	5.15	6.70	5.95	0.47	0.67
3. Number of Leaves (per plant)	8.00	7.67	7.50	5.33	0.27	0.37
4. Length of the Largest Leaf (in cms)	22.00	20.93	20.50	16.48	1.41	1.88
5. Dry Weights (in gms)						
a. Shoots	4.08	3.50	3.30	3.13	0.36	0.49
b. Roots	1.55	1.30	1.05	0.95	0.84	1.16
6. Length of the Flower Stalk (in cms)	2.48	1.87	1.47	0	1.03	1.06
7. Number of Open Flowers and Green Buds (per plant)	3.67	2.67	2.00	0	Not Significant	
8. Shoot/Root Ratio	2.60	2.60	3.10	3.30	-	-

*All measurements were taken one month after application and from six replications per treatment.

Figure : 2

Figure 2.

Alteration in appearance, growth and development of Tomato Seedlings as a result of foliar applications of solutions of maleic hydrazide at 1000 p.p.m.

<u>Left</u>: Control Right: Treated

(Note the reduction in height, number of leaves and activity of lateral buds in treated plants.)

Applications of solutions of maleic hydrazide were carried out at a time when seedlings were 47 days old. Photographs taken one month after application.

Figure : 3

Figure 3.

Foliar applications of solutions of maleic hydrazide to young tomato seedlings at 1000 p.p.m. resulted in injury to the apical meristem of shoot, malformation of leaves arising from such meristem and inhibition of flowering.

Upper: Control plants showing normal activity of terminal meristem of the shoot, normal leaves and flower buds.

Lower: Plants treated with solutions of 1000 p.p.m. maleic hydrazide showing injury to the terminal meristem, malformed leaves and inhibition of flowering.

Solutions of maleic hydrazide were applied as a foliar spray to 47 day old seedlings of tomato and photographs were taken one month after application.

Plants receiving 1000 p.p.m. solutions of maleic hydrazide as a foliar spray were distinctly different in appearance from that of the control and other treated plants (Figure 2). The terminal meristem of the shoot was most severely affected in these plants. The leaves arising from the terminal meristem were malformed and showed signs of injury. The lateral buds were activated and flowering was inhibited. No signs of flower buds could be detected by a visual observation (Figure 3).

The growth measurements taken in plants treated with solutions of maleic hydrazide at 1000 p.p.m. were compared with those of the control. Except for the dry root weights, the differences between them for all the growth measurements were significant at the 1% level (Table III).

The differences in the growth measurements between treated plants, when statistically evaluated indicated the following:

1. The differences in height, stem diameter, number of leaves per plant and the length of the largest leaf, between plants treated with 1000 p.p.m. solutions of MH and plants treated with other concentrations were significant at the 1% level.

2. Plants treated with 100 p.p.m. solutions of MH as compared to plants treated with 10 p.p.m. solutions of MH had a significantly increased stem diameter and reduced height.

Differences between them for other growth measurements made and compared were not significant.

B. Nutrient element contents:

The contents of some nutrient elements of maleic hydrazide treated and control plants, determined one month after application of the chemical are presented in Table IV. The nutrient elements are expressed as a percentage as well as in grams or milligrams as the case may be, based on the dry weights of plants. (For dry weights, Appendix Table 2). All comparisons between treatments are made on data expressed on dry weight basis of plants. The indications are that maleic hydrazide treated plants show a tendency for lesser accumulation of nutrient elements as compared to the control.

Among the treated plants the tendency for accumulation of nutrient elements were:

1. In so far as the roots were concerned, all the treated plants for all the nutrient elements determined, showed a tendency towards a decreased amount of accumulation with increasing concentration of the chemical.
2. In shoots such a tendency was observed only for boron.
3. The combined amounts of nutrient elements of shoots and roots indicated for potassium, phosphorus, boron and manganese, the contents

Table IV: Some Nutrient Element Contents in Shoots and Roots of Tomato, Determined One Month After Application of Maleic Hydrazide. Applications Made as a Foliar Spray to 47 Day Old Seedlings:

Nutrient Elements	Shoots %	Shoots Weight basis	Roots %	Roots Weight basis	Total (Shoots + Roots, wt. basis
NITROGEN					
Control	1.29	52.63	1.14	17.67	70.30
MH - 1	1.24	43.40	1.47	19.11	62.51
MH - 2	1.13	37.29	1.50	15.75	53.04
MH - 3	1.46	45.70	1.12	10.64	56.34
POTASSIUM					
Control	3.50	142.80	2.75	42.63	185.43
MH - 1	3.30	115.50	2.50	32.50	148.00
MH - 2	3.14	103.62	2.58	27.09	130.71
MH - 3	3.39	106.10	2.05	19.48	125.58
CALCIUM					
Control	2.07	84.46	1.16	17.98	102.44
MH - 1	2.03	71.05	1.23	15.99	87.04
MH - 2	2.35	77.55	1.16	12.18	89.73
MH - 3	2.30	71.99	1.09	10.36	82.35
MAGNESIUM					
Control	0.62	25.30	0.69	10.70	36.00
MH - 1	0.57	19.95	0.71	9.36	29.31
MH - 2	0.77	25.41	0.71	7.46	32.87
MH - 3	0.79	24.73	0.60	5.70	30.43
PHOSPHORUS					
Control	0.23	9.38	0.30	4.65	14.03
MH - 1	0.20	7.00	0.29	3.77	10.77
MH - 2	0.22	7.26	0.29	3.05	10.31
MH - 3	0.23	7.20	0.26	2.47	9.67

Table continued next page.

Table IV (Continued)

Nutrient Elements	Shoots %	Shoots Weight basis	Roots %	Roots Weight basis	Total (Shoots + Roots, wt. basis
BORON					
Control	0.0027	110.16	0.0028	43.40	153.56
MH - 1	0.0025	87.50	0.0021	27.30	114.80
MH - 2	0.0026	85.80	0.0023	24.15	109.95
MH - 3	0.0027	84.51	0.0021	19.95	104.46
MANGANESE					
Control	0.0035	142.80	0.0053	82.15	224.95
MH - 1	0.0029	101.50	0.0041	53.30	154.80
MH - 2	0.0031	102.30	0.0040	42.00	144.30
MH - 3	0.0032	100.16	0.0039	37.05	137.21
COPPER					
Control	0.0027	110.16	0.0054	83.70	193.86
MH - 1	0.0022	77.00	0.0048	62.40	139.40
MH - 2	0.0021	69.30	0.0042	44.10	113.40
MH - 3	0.0027	84.51	0.0036	34.20	118.71

MH - Maleic hydrazide

MH - 1, at 10 p.p.m.
MH - 2, at 100 p.p.m.
MH - 3, at 1000 p.p.m.

Nitrogen, Potassium, Calcium, Magnesium and Phosphorus expressed in milligrams. Boron, Manganese and Copper expressed in micrograms.

decreased with increase in concentration of maleic hydrazide.

C. Rate and total accumulation of phosphorus:

Applications of solutions of maleic hydrazide as a foliar spray at 1000 p.p.m. to tomato plants grown in a nutrient culture with varying levels of phosphorus resulted in reduced uptake and accumulation of phosphorus (Table V).

Table V: Rate and Total Accumulation of Phosphorus in Tomato (Michigan Ohio Hybrid) When Grown Under Varying Levels of Phosphorus in a Nutrient Culture, With and Without Maleic Hydrazide. Maleic Hydrazide Applied as a Foliar Spray When Seedlings Were 30 Days Old:

Level of 'P' in p.p.m.	Total Accumulation of 'P' (in mgs)		Rate of Accumulation of 'P' (mgs)		Efficiency of Accumulation as a percentage of Control	
	Control	Treated	Control	Treated	Control	Treated
16	19.14	13.20	17.14	11.20	100	65.34
32	26.42	22.46	23.66	19.70	100	83.26
64	35.66	27.84	30.26	22.44	100	74.15
128	46.00	32.00	40.32	26.32	100	65.33

'P' - Phosphorus.

The efficiency of accumulation of phosphorus in treated plants ranged between 65.33 to 83.26 percent and was influenced by the level of phosphorus in the nutrient culture. In both the control and treated plants, the rate and total accumulation of phosphorus increased with the increase in level of phosphorus in the nutrient culture (Table V).

Observations made on the growth and development of the tomato seedlings in the same experimemt indicated the following:

1. With decrease in level of phosphorus in the nutrient culture, the length of the roots decreased. With application of maleic hydrazide as a foliar spray this was further inhibited (Figure 4).
2. Shoot growth was also inhibited in tomato seedling irrespective of level of phosphorus in the nutrient culture as a result of application of maleic hydrazide (Figure 5).
3. The most pronounced effect of maleic hydrazide was seen on the leaves in all the seedlings in all the levels of phosphorus. The number of leaves per plant was reduced. The color, texture, margin of leaves and venation were also influenced. Leaves were dark green, leathery and brittle. Venation was less prominent and the axillary angles that leaves made with the stem were narrower, as compared to the controls (Figure 5).

Figure: 4

Figure 4.

Decrease in length of roots in tomato seedlings with decrease in level of phosphorus in the nutrient culture. With foliar applications of solutions of maleic hydrazide at 1000 p.p.m. this was further inhibited.

Roots from treated plants alternated with their controls. Left extreme is the control seedlings grown in 128 p.p.m. level of phosphorus showing the root growth. They are followed by seedlings grown in 64 and 16 p.p.m. levels of phosphorus.

Applications of solutions of maleic hydrazide were carried out when tomato seedlings were 30 days old and photographs taken 28 days after application.

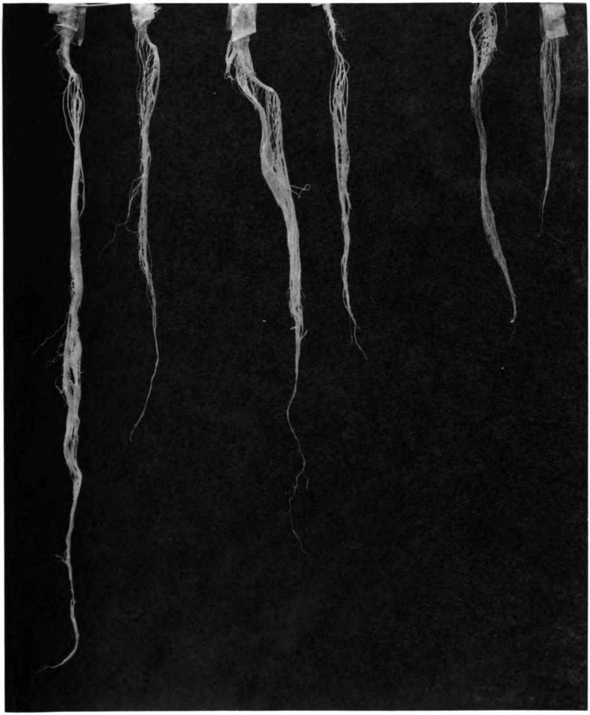

Figure: 5

Figure 5.

Foliar applications of solutions of maleic hydrazide at 1000 p.p.m. to young tomato seedlings growing in a nutrient culture with varying levels of phosphorus resulted in inhibition of shoot growth and alteration in color, texture, lobing of margin, venation and orientation of leaves to the stem.

Upper: Treated tomato seedlings in all levels of phosphorus showing inhibition of shoot growth. Treated plants alternated with controls. Left extreme is the control seedling growing in 16 p.p.m. level of phosphorus. It is followed by seedlings grown in 64 and 128 p.p.m. level of phosphorus.

Lower: A comparison of treated plants with the control for showing the difference in number of leaves, lobing of margins and orientation of leaves with the stem.

Left: Treated   Right: Control

Photographs were taken 28 days after application of solutions of maleic hydrazide at 1000 p.p.m. to 30 day old seedlings.


125 PP

It was evident from the observations made that maleic hydrazide applications as a foliar spray resulted in the inhibition of growth of young tomato seedlings. Furthermore, by increasing the level of phosphorus in the nutrient culture, it was not possible to relieve completely the inhibition induced by maleic hydrazide.

D. Influence of maleic hydrazide on root hairs and respiration of roots in tomato:

When solutions of maleic hydrazide were applied as a foliar spray at 1000 p.p.m. to one month old tomato seedlings, the development of root-hairs and respiration of roots were influenced. Following application, examination of plants made within a week revealed that root-hairs in treated plants were few and they had a tendency to be located near the tip of the roots. Rates of respiration in treated root tips determined 192 hours after application of the chemical as compared to the root tips of non-treated plants, showed a marked reduction (Table VI, Appendix Table 4).

Table VI: Respiration of Roots in Tomato (Michigan Ohio Hybrid) as Influenced by Foliar Applications of Maleic Hydrazide. Applications Made When Seedlings Were 30 Days Old:

Treatments	Oxygen Consumed* (in microliters/milligram dry weight)
1. Control	9.04
2. Treated	1.30

*192 hours after application of maleic hydrazide.

DISCUSSION

Fruit-Set in Tomato (John Baer) Grown Under High Night Temperature:

When tomatoes are grown under night temperatures higher than optimal for their growth, they are subjected to an unfavorable environment. Under this condition, vegetative growth becomes dominant, fewer flowers are produced, and flower abscission is excessively high. All these result in poor or no fruit-set (62). Such was the case in the present experiments also, when tomatoes (John Baer) were grown under high night temperature, 70^{o} - 80^{o}F (Tables I, II).

Under the aforesaid condition, independent foliar applications of maleic hydrazide or growth regulator treatment to fully opened flowers fail to increase fruit-set, but their combinations resulted in significant increase of fruit-set (Tables II, IIA). The indications of these results are best appraised in the light of factors associated with fruit-set under high night temperature in tomato. According to Went (62) the crux of the fruit-set problem in tomato under high night temperature lies in the critical availability of carbohydrates and the manner in which it is subsequently utilized. The poor fruit-set under this condition arises out of the available carbohydrates being made use of in an excessive vegetative growth to the detriment of fruit-set (62). By reducing vegetative growth, accumulation of carbohydrates is favored which improves fruit-set. Applications of maleic hydrazide result in the reduction of vegetative growth, retardation of respiration and accumulation of carbohydrates in many plants. Since applications of maleic hydratzide alone did not result in better fruit-set, there are two possible explanations. One is, the application of maleic hydrazie failed to reduce vegetative growth and increase carbohydrate accumulation adequately. The second reason is that, besides deficiency of carbohydrates some other secondary factor is involved. Growth regulator applications are often known to improve fruit-set where failure of pollination exists (48). Since combined treatments of maleic hydrazide and growth regulator have been shown to increase fruit-set, it is surmised that under high night temperature besides lack of adequate availability of carbohydrates, failure of pollination also exists. Howlett (29, 30) has reported that the deficiency of carbohydrates in tomatoes, induces pollon sterility.

Foliar applications of maleic hydrazide combined with growth regulator treatment, gave significantly better fruit-set as compared to growth regulator treatment alone, (Tables II, IIA). Failure of pollination has been indicated to be a secondary factor associated with high night temperature. Then it is only reasonable to attribute a greater significance to the foliar applications of maleic hydrazide for the increased fruit-set recorded in the experiment. Hence the indications are that maleic hydrazide can be used to counteract the unfavorable influence of high night temperature. Foliar applications of solutions of maleic hydrazide at 2000 p.p.m. to citrus seedlings helped them to withstand as low a temperature as 22°F (68). The principle was to provide for the accumulation of carbohydrates to overcome the effects of low temperatures.

Learner and Wittwer (35), making soil applications of maleic hydrazide to young tomato transplants concluded that the chief objection in using this chemical for hardening practices was that it reduced early yields. Roots are more sensitive than shoots in their response to maleic hydrazide and treatment of young seedlings are known to result in undesirable morphological changes (4, 9, 31). This indicates that the time and method of applications of maleic hydrazide are important when used for hardening practices. In the present experiments maleic hydrazide was used as a foliar spray after the plants started to flower. The flower clusters as well as the soil were protected from the chemical sprays.

Physiological Responses of Tomato Seedlings to Foliar Applications of Maleic Hydrazide:

When young tomato seedlings were treated with foliar sprays of maleic hydrazide their growth and development were altered. The extent to which they were influenced depended upon the concentrations of the chemical used. At the highest concentration (1000 p.p.m. solutions), both vegetative and reproductive growth were affected (Table III, Figures 2,3). At higher concentrations the chemical induced inhibition of growth. These observations are in agreement with those of others who have reported on inhibition of plant growth in tomato and other plants ensuing foliar applications of maleic hydrazide (12, 13, 18, 44, 53).

The external changes observed in growth and development of tomato seedlings following foliar applications of maleic hydrazide are possibly the relfections of alteration in their physiological activity. Such an assumption appears to be logical when the accumulation of nutrient element, root growth, extent and nature of root hairs and root tips present and respiration of roots in treated plants are all considered.

Following foliar applications of maleic hydrazide in tomatoes the root elongation was inhibited, and the root tips were found to show injuries as well as necrosis. The roots were shorter and fewer as compared to the non-treated plants. The chemical appeared to act as a root pruning agent. Root pruning is known to produce vegetative growth and favor accumulation of carbohydrates (82). One of the probable reasons for inhibition of vegetative growth and accumulation of carbohydrates in maleic hydrazide treated plants, which has been frequently reported, could be due to its effect on the root tips and roots in general.

Maleic hydrazide treated plants were found to have fewer root hairs as compared to the non-treated plants. The root hairs instead of being present a few millimeters behind the root tips in the 'zone of maturation', appeared at the very tip of the roots. Either the region of elongation was reduced to such an extent as to make the root hairs in the 'zone of maturation' come closer to the root tips or the location of root hairs were possibly altered.

The root hairs play a vital role in the absorption of water and the nutrient elements. When the number and location of root hairs appeared to be altered, it is conceivable that the uptake of nutrient elements could be affected. The experiments on the accumulation of some important nutrient elements following foliar applications of maleic hydrazide to the tomato plants showed that they accumulated lesser amounts of nitrogen, potassium, phosphorus, magnesium, boron, maganese and copper as compared to the non-treated plants (Table IV).

Reduced accumulation of nutrient elements observed in the treated plants in the present experiments can be considered to reflect the efficiency of uptake of nutrients by the roots, from the media. It then suggests that factors associated with the absorption of nutrients, such as membrane permeability, osmotic pressure and exchange capacity of the roots are likely to be influenced.

Since uptake of nutrient elements are affected by treatment with maleic hydrazide, some of the growth responses resulting by its application could be secondary effects not attributable to the chemical alone.

Foliar sprays of maleic hydrazide to the tomato plants grown in a nutrient culture, with varying levels of phosphorus, have shown that the efficiency of uptake, the rate and accumulation of phosphorus were retarded (Table V). Increase in level of phosphorus in the nutrient culture did not help to completely overcome the inhibition induced by maleic hydrazide. This indicates that the roots are unable to take up phosphorus as efficiently as the non-treated plants from the media. Uptake of phosphorus depends upon an 'active uptake' mechanism involving the use of respiratory energy (32, 41). A few workers have suggested that the inhibitory effects of maleic hydrazide on plant respiration are reflected by the reduced uptake of water and phosphorus (55, 65).

Foliar applications of maleic hydrazide resulted in a reduction of respiration of the roots (Table VI). Naylor and Davis (45, 46), by treating excised roots of several species of plants with maleic hydrazide came to similar conclusions. The inhibition of respiration in higher plants is frequently accompanied by cessation of growth or undesirable morphological changes (31). Hence the inhibition of growth in the tomato plants treated with maleic hydrazide observed, could be attributable to its effect on root respiration.

Maleic hydrazide accumulates in actively growing meristem, affecting cell division and growth (8, 18, 67). In the shoots of a young tomato plant, the most active meristem is the apical meristem. On the other hand in roots for every root tip we have an active root meristem and roots being more in number it can be expected that the chemical exerts a greater influence on the roots than on any other organ.

The physiological changes observed in tomatoes following foliar applications of maleic hydrazide appears to be mainly due to its effect on the root growth, root hairs, root tips, root meristems and roots in general.

SUMMARY

Greenhouse experiments were carried out from the fall of 1958 to the spring of 1960, to study some of the physiological responses of tomato following foliar applications of maleic hydrazide. Fruit-set in tomato under high night temperature, as influenced by such applications was of particular interest. Other responses investigated were, general growth responses, accumulation of certain nutrient elements, and respiration of roots in maleic hydrazide treated plants.

The following were the noteworthy results recorded:

1. Tomatoes (John Baer) grown under high night temperature (70^{o} - 80^{o}F), produced few flowers, a high flower abscission and a poor fruit-set.
2. Foliar applications of maleic hydrazide (20 p.p.m.) followed by growth regulator treatment (50 p.p.m., BNOA) to fully opened flowers increased fruit-set significantly.
3. It has been indicated that under high night temperature, failure of pollination is a secondary factor in influencing fruit-set in the tomato.
4. The increased fruit-set recorded in tomato

under high night temperature, was mainly attributed to foliar applications of maleic hydrazide. It appears that maleic hydrazide counteracts the unfavorable influence of high temperature on plants.

5. Foliar applications of solutions of 1000 p.p.m. of maleic hydrazide to young tomato seedlings resulted in the inhibition of their vegetative and reproductive growth. The most notable effects were retardations of stem and root elongation, increase in stem diameter , lesser number of leaves per plant and decreased length of leaves. Alteration in color, texture and venation of leaves were also noted.

6. Maleic hydrazide treated plants tend to accumulate lesser amounts of some important nutrient elements such as nitrogen, potassium, phosphorus, clacium, magnesium, boron, copper and maganese.

7. The rate and total accumulation of phosphorus were retarded, when tomatoes were grown in a nutrient culture with varying levels of phosphorus and treated with maleic hydrazide. The inhibition induced by maleic hydrazide could not be overcome effectively by increasing the level of phosphorus in the

nutrient culture. Roots of the treated plants were unable to absorb phosphorus efficiently from the media.

8. Foliar applications of maleic hydrazide to young tomato seedlings influenced the root-tips, root hairs, and respiration of roots. Many root-tips showed injury as well as necrosis. Root hairs were few and appeared at the very tip of the root. Root elongation and respiration of roots were also inhibited.

9. It is believed that maleic hydrazide alters the physiology of tomato plants and induces inhibition of growth by affecting the root-tips, root hairs, roots and respiration of the roots.

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A P P E N D I X

Table 1: Influence of High Night Temperature (70°-$80^{\circ}F$) on the Number of Flowers Produced per Cluster in Tomato (John Baer):

Experiment Number	Season	Number of plants	Number of flowers	Average/cluster
1.	Winter 1958-59	118	401	3.4
2.	Spring 1959	48	173	3.6

Table 2: Influence of Varying Concentrations of Maleic Hydrazide on Dry Weights of Shoots and Roots of Tomato (John Baer). Maleic Hydrazide Applied as a Foliar Spray to 47 Day Old Seedlings, and Weights Determined One Month After Application:

Treatment	Average dry weight* of shoots (in gms).	Average dry weight* of roots (in gms).
Control	4.08	1.55
MH - 10 p.p.m.	3.50	1.30
MH - 100 p.p.m.	3.30	1.05
MH - 1000 p.p.m.	3.13	0.95

*All weights from an average of six replicates for each treatment.

MH - Maleic hydrazide.

Table 3: Effect of Foliar Applications of Maleic Hydrazide on the Dry Weights of Tomato (Michigan Ohio Hybrid) Grown in a Nutrient Culture With Varying Levels of Phosphorus. Maleic Hydrazide was Applied to 30 Day Old Seedlings and Weights Recorded at the Time of Treatment and 28 Days Following Treatment:

Date	Level of Phosphorus (p.p.m.)	Dry Weights* (in gms)			
December 6th, 1959 **	128	0.49			
	64	0.50			
	32	0.46			
	16	0.40			
		Shoots		Roots	
		Control	Treated	Control	Treated
January 3rd, 1960	128	4.00	3.20	1.00	0.60
	64	4.60	3.60	0.80	0.40
	32	3.80	3.40	0.80	0.40
	16	3.00	3.00	0.60	0.30

**Weights on the whole plant basis for plants removed on December 6th.

*All weights are averages from three replicates, each replicate consisting of two plants.

Table 4: Effect of Foliar Applications of Maleic Hydrazide on the Phosphorus Contents of Tomato (Michigan Ohio Hybrid) Grown in a Nutrient Culture With Varying Levels of Phosphorus. Maleic Hydrazide Was Applied to 30 Day Old Seedlings and Phosphorus Content Determined at the Time of Treatment, and 28 Days Following Treatment:

Date	Level of Phosphorus (p.p.m.)	Concentration of phosphorus (in percent)
December 6th, 1959	128	1.16
	64	1.08
	32	0.60
	16	0.50

Date	Level of Phosphorus (p.p.m.)	Shoots		Roots	
		Control	Treated	Control	Treated
January 3rd, 1960	128	0.80	0.73	1.40	1.44
	64	0.61	0.66	0.95	1.20
	32	0.51	0.57	0.88	0.77
	16	0.47	0.38	0.84	0.60

*Initial phosphorus content determined on whole plant basis for plants removed on December 6th, 1959.

Table 5: Effect of Foliar Applications of Maleic Hydrazide on Respiration of Tomato (Michigan Ohio Hybrid) Root-Tips. Maleic Hydrazide was Applied at 1000 p.p.m. to 30 Day Old Seedlings, and Determinations of Rates of Respiration Made 192 Hours After Applications:

Flask Number	Readings of manometer				
	Initial 4.00 pm.	4.15	4.32	4.50	Final 5.13
I Control	249	238	238	238	234
II "	249.5	239	235	234	234
IV Treated	250	248	248	248	248
V "	249.5	247	247	247	247

20 root-tips of 1cm each were used per flask. Final consumption of oxygen expressed in microliters on milligram dry weight of root-tips.