

DOCTORAL DISSERTATION SERIES

TITLE GROWTH AND DEVELOPMENT OF
VEGETABLE CROPS AS INFLUENCED BY FOLIAR
APPLICATION OF SUCROSE AND MAJOR NUTRIENT
ELEMENTS

AUTHOR BENNIE DOUGLAS MAYBERRY

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GROWTH AND DEVELOPMENT OF VEGETABLE CROPS AS INFLUENCED
BY FOLIAGE APPLICATION OF SUCROSE AND MAJOR
NUTRIENT ELEMENTS

By

Bennie Douglas Mayberry

A THESIS

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Dedicated to my wife, Selena,
without whose encouragement and sacrifice this
work would not have been possible.

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TABLE OF CONTENTS

	Page
I. ACKNOWLEDGEMENTS	ii
II. INTRODUCTION	viii
III. REVIEW OF LITERATURE	1
IV. PROBLEM FOR INVESTIGATION	5
V. GENERAL METHODS AND MATERIALS	7
VI. EXPERIMENTAL	
A. Sucrose sprays	
1. Interrelations of temperature and photoperiod on the response of greenhouse tomatoes to foliar applications of sucrose	9
2. The effects of sucrose and the "Missouri Method" of pruning on the yield of greenhouse tomatoes .	15
B. Sucrose and Urea Sprays	21
C. Urea Sprays	
1. Tolerances of certain vegetable crops to urea .	35
2. The effects of urea sprays on the growth of beans and cucumbers in the greenhouse	37
3. The effects of temperature on the utilization of foliar applied urea by greenhouse-grown celery	43
4. The yield of early field celery as affected by repeated spray applications of urea	49
D. All-Soluble Complete Fertilizer Sprays	54
E. Isotopes and Foliar Applications of Nutrients	
1. The absorption and translocation of leaf applied phosphorus and potassium by bean and squash seedlings	60

2. The mobilization of radioactive phosphorus by the fruits of greenhouse tomatoes from leaf and soil applications as affected by temperature	66
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VII. DISCUSSION

A. Mechanism of foliar absorption and translocation	74
B. Utilization of foliar applied sucrose	79
C. Utilization of foliar applied urea	82
D. Response to foliar applied all-soluble complete fertilizers	83
E. Utilization of foliar applied isotopic phosphorus and potassium	84

VIII. SUMMARY AND CONCLUSION	89 -91
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IX. LITERATURE CITED	92
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LIST OF TABLES

	Page
Table I. Dry Weight of Greenhouse Tomato Plants in Response to Foliage Applications of Sucrose when Interacted with Temperature and Photoperiod	12
Table II. The Effects of Sucrose, Growth Regulators and the "Missouri Method" of Pruning on the Yield of Greenhouse Tomatoes	18
Table III. Explanation of Varietal Symbols Used in Table IV . .	19
Table IV. The Yield of Ten Varieties of Greenhouse Tomatoes as Affected by Sucrose, "Hormones" and the "Missouri Method" of Pruning	20
Table V. Early Yield of Field Tomatoes as Affected by Sucrose Solution Applied to the Foliage of Transplants (1949)	25
Table VI. Total Yield of Field Tomatoes as Affected by Sucrose Solution Applied to the Foliage of Transplants (1949)	26
Table VII. The Effect of Urea Sprays on the Early Yield of Field Tomatoes (1949)	27
Table VIII. The Effect of Urea Sprays on the Total Yield of Field Tomatoes (1949)	28
Table IX. Design of Experiment B 1950	30
Table X. The Yield of Two Varieties of Tomatoes as Affected by Sucrose Treatments	33
Table XI. The Effect of Fertilizer Treatments on the Yield of Two Varieties of Tomatoes	34
Table XII. Degree of Leaf Injury on Cucumbers, Beans, Tomatoes and Celery Resulting from Various Concentrations of Urea Sprays	36
Table XIII. The Effect of Soil and Leaf Applied Nitrogen on the Fresh Weight of Beans and Cucumbers	41

	Page
Table XIV. The Dry Weight of Two Varieties of Greenhouse-Grown Celery as Affected by Method of Application of Nitrogen and Night Temperature	46
Table XV. The Effect of Soil and Leaf Applied Nitrogen on the Dry Weight of Cornell #19 and Utah #15 Celery Grown in the Greenhouse	47
Table XVI. The Dry Weights of Greenhouse-Grown Celery as Affected by Method of Application of Nitrogen and Night Temperature	48
Table XVII. The Effect of Soil and Leaf Nitrogen on the Yield of Early Field Celery	52
Table XVIII. The Yield of Two Varieties of Celery as Affected by Soil and Foliar Applied Nitrogen	53
Table XIX. Description of All-Soluble Fertilizer Materials . .	57
Table XX. The Effect of Soluble Fertilizer Sprays and Steam Sterilization on the Yield of Greenhouse Tomatoes .	58
Table XXI. Correlation Between Fertilizer Analysis of Nutritional Sprays and Response by Greenhouse Tomatoes in Terms of Yield	59
Table XXII. Influence of Night Temperatures on the Movement of Radioactive Phosphorus into the Tomato Fruits from Soil and Leaf Applications	73

LIST OF FIGURES

	Page
Figure 1. The response of tomato plants to applications of sucrose when grown at different photoperiods and temperatures	13
Figure 2. Sucrose treated plants interacted with photoperiod and temperature	14
Figure 3. The relative growth of bean plants receiving leaf and soil nitrogen	38
Figure 4. Comparative response of cucumbers to applications of soil and leaf nitrogen	40
Figure 5. Comparative growth response of tomato plants to applications of nitrogen to the leaves and the soil . .	42
Figure 6A. Autoradiograms of bean and squash plants following treatment of one of the primary leaves of the bean and the primary leaf of the squash with radioactive phosphorus (P^{32})	63
Figure 6B. Autoradiograms of bean and squash plants following treatment of one of the primary leaves of the bean and the primary leaf of the squash with radioactive potassium (K^{42})	63
Figure 7A. Translocation of foliar applied radioactive potassium from leaf treated of bean and squash plants to the remainder of the plant at various time intervals subsequent to treatment	65
Figure 7B. Translocation of foliar applied radioactive potassium from leaf treated of bean and squash plants to the remainder of the plant at various time intervals subsequent to treatment	65
Figure 8. Method used in dipping plants in radioactive solutions	68
Figure 9. Potato plant placed in horizontal position after dipping to prevent excess solution from falling on the soil	69
Figure 10. Potato plant placed in pan and watered from below to guard against washing radioactive materials from the leaves onto the soil	70
Figure 11. Autoradiograms of bean plants showing the distribution of radioactive phosphorus in the plant subsequent to foliage and soil applications	85

INTRODUCTION

Until the close of the nineteenth century it was generally assumed that the only means of nutrient absorption by plants was through the roots. Early in the twentieth century, however, it became evident that copper, zinc, and iron deficiencies in Citrus could be partially corrected by means of applying these nutrients to the leaves. The lack of iron available in the soil for pineapples has been overcome by spraying the plants with an eight per cent solution of ferrous sulphate. (18) More recently investigators in England (3) and in this country (5) found that magnesium deficiencies in mature apple trees may be corrected by foliage applications of Epsom salts in instances where soil application proved of no benefit. Still more recently, investigators (4) at the Cornell Agricultural Experiment Station have maintained nitrogen balance in apple trees by means of foliage sprays of urea.

The general anatomical and physiological similarities of the foliage of higher plants suggest that nutrients may be applied with benefit to the leaves of herbaceous plants. With this in mind, a study of the possibilities of foliar applications of sucrose, nitrogen, phosphorus, and potassium was conducted with certain vegetable crops.

REVIEW OF LITERATURE

Leaf feeding vegetable crops is not an established practice. To this writing, little information on the subject is available. Literature on the application of nutrients to the leaves of vegetable crops is extremely limited. Some progress has been made in leaf feeding certain fruit crops and will be referred to in this study.

General Nutrient Sprays

Foliar application of zinc, manganese, and copper have been used successfully to correct deficiencies in Citrus fruits (19). Hamilton, Palmiter, and Weaver (12) have suggested that fermete (Ferric-dimethyldithiocarbamate) may be of nutritional value when used as an insecticide on trees. According to them, it may be the most promising substitute for sulfur and copper in the control of apple diseases.

Boynton (5) has reported that four cover sprays of Epsom salts (16 lbs./100 gal. H_2O) eliminated blotch on magnesium deficient Cortland apple leaves, and built up the leaf magnesium above 0.25 per cent of dry weight in the year of spraying.

The possibility that phosphorus, as contained in certain pesticides, may be of nutritional value has been suggested by Wolfenbarger (34).

Recent reports (as noted above) indicate a growing interest in the use of nutritional sprays. Silberstein and Wittwer (25) have indicated that some advantages accredited to nutritional foliar sprays are: a greater control over the desired fruiting and vegetative response, less fertilizer used, and simplified application by combining with pesticides.

Sucrose Sprays

In tracing the path of carbon in photosynthesis, Calvin and Benson (6) reported that the first free sugar formed was sucrose. Factors effecting photosynthetic activity subsequently limit the rate and extent of sucrose formation. Among the most important of these limiting factors are duration and intensity of light. Went and Carter (29) have suggested that intact leaves of the tomato absorbed sucrose readily; apparently through the whole surface and not especially through the stomata. The lower surface was found to be more permeable than the upper. Applied sucrose caused a greater response when treated plants were grown under conditions of high temperature and low light intensity.

Emmert and Klinker (9) indicated that the addition of equal molar amounts of sucrose to urea sprays increased the tolerance of tomatoes for urea from five to fifty pounds per 100 gallons of water without marginal leaf burning.

Nitrogenous Spray Materials

In certain crops, the nitrogen requirement varies with the stages of development. The apple is a typical example. Hamilton, Palmiter and Anderson (13) have shown that by using urea sprays, the nitrogen supply may be increased in the early spring and summer when it is probably needed most, and result in a low reserve in the fall so as not to interfere with good fruit coloring. With apple trees, foliage sprays may be especially beneficial during periods of low rainfall or in dry areas. Hamilton, Palmiter, and Anderson reported also that urea may be applied to apple trees with insecticides without injury.

After three spray applications of urea to apple trees, Fisher and Cook (11) noticed that leaf nitrogen and chlorophyll were higher than in comparable trees which had received the same amount on the soil. Three urea sprays caused the trees to set and produced a yield of fruit which was greater than that obtained on those which had received soil application of comparable poundage of nitrogen.

Review of Phosphorus Literature

Biddulph (2) observes that when radioactive phosphorus is injected into the bean leaf, the per cent of migration and distribution varied throughout the day. The initial direction of flow was predominantly downward with the greatest total movement at or near 10 A.M., and with least at 10 P.M.. Upward maximum movement was near noon. Light was associated with migration, but maxima did not coincide.

Arnon, Stout, and Sipos (1) have shown that after forty minutes radioactive phosphorus which was absorbed by the roots was detected in the upper leaves of the tomato plants six feet tall. Fully ripe fruit attached to vines continued to absorb small amounts of phosphorus. Under such conditions, the newly absorbed phosphorus was limited to the pulp, whereas when absorbed by green fruits it was concentrated in both the seed and pulp. The younger the fruit the greater the capacity to absorb phosphorus. Under conditions of restricted phosphorus supply, the fruit whether ripe or green continued to draw on the phosphorus present in the leaves.

In a parted root experiment Hevesy (16) showed that there is a slow exudation of phosphorus from the root tips to the solution in which they are growing. This apparently, indicates that, when using radioactive phosphorus in root absorption studies, specific activity of the plant parts does not necessarily represent net uptake because at the time that P^{32} is being absorbed P^{31} (at a much slower rate) is being lost to the plant medium.

PROBLEM FOR INVESTIGATION

The study consisted of two phases. The first had to do with an evaluation of crop response to foliar applied sucrose, and the second, with absorption, translocation, and utilization by certain vegetable crops of foliar applied nitrogen, phosphorus, and potassium.

Foliar Application of Sucrose

In Michigan, the usual limiting factors in the growth of greenhouse crops during the fall, winter, and spring months are intensity and duration of light. This light deficiency limits photosynthetic activity which in turn reduces the amount of food elaborated by the leaves, and consequently limits growth and development. It may be assumed that if the carbohydrates which are normally synthesized by the leaves of the plant are supplemented by foliage sprays of sucrose, the effects of light deficiency may be partially overcome. This possibility has been suggested by Went and his co-workers. The procedure was to test the validity of this assumption on greenhouse grown tomatoes. A second problem involved that of carbohydrate reserves in field-set tomato plants. The common practice of "hardening" transplants has as one objective the accumulation of carbohydrate reserves. The plants are subjected to low temperatures, low moisture, low nitrogen, and other fertilizers are withheld. New growth is thus suppressed permitting carbohydrates to accumulate. The possibility of increasing the carbohydrate reserves in tomato transplants

by sucrose sprays, and using as an index recovery following field transplanting, was investigated.

Foliar Application of Nitrogen, Phosphorus and Potassium

Nitrogen in the form of urea has been successfully used at a concentration of five pounds per 100 gallons of water in one calyx and two subsequent early cover sprays to cause positive responses by McIntosh apples (4). Magnesium and copper have also been successfully applied to apple trees in foliar sprays. Some conditions under which it has been suggested that nutritional sprays may probably be advantageous follow:

1. When soil temperature is low thereby limiting the extent and rate of microbial activity.
2. When soil moisture is in excess, limiting air circulation and root absorption.
3. When immediate response is needed and side dressing is not feasible.
4. When nutrients may be combined with pest control sprays to reduce operation cost.
5. When less material is required to accomplish a desired result than would be required on the soil.
6. When there is danger of fixation or lack of movement in the soil.

The objectives in this phase of the study were to evaluate the apparent advantages of nutritional foliage sprays in supplying nitrogen, phosphorus, and potassium to certain vegetable crops.

GENERAL METHODS AND MATERIALS

Plants for the experimental studies were grown in both greenhouse and the field. The soil type, temperature, and kind of crop varied with each experiment depending upon the specific phase of the work involved. These details will be given fully in the discussion of each experiment.

In all sucrose studies, a 10 per cent solution was made containing 0.1 per cent dreft as a spreader. For convenience the plants were dipped rather than sprayed in order to provide more complete leaf coverage and the greater ease in preventing soil contamination.

"NuGreen", a urea preparation¹ containing 44 per cent nitrogen, was used in studying the utilization of foliar applications of this nutrient. Spray concentration varied from 0.45 to 1.0 per cent depending upon the crop. In the initial experiment on tolerance, concentrations ranged from 0.25 to 1.0 per cent. Dreft, at a concentration of 0.1 per cent was used as a wetting agent.

Radioactive phosphorus² was used in studying the rate and extent of leaf absorption and subsequent translocation of this nutrient. To a 0.3 per cent solution of stable phosphoric acid, radioactive phosphorus was added to make concentrations ranging from 0.1 to 2.0 microcuries per milliliter. One tenth of one per cent dreft was also added as a wetting agent.

¹ Generously supplied by E. I. duPont de Nemours & Co., (Inc.)
Wilmington, Delaware.

² Purchased as a low normality ortho-phosphoric acid from the Isotope Division of the U. S. Atomic Energy Commission, Oak Ridge, Tennessee.

The potassium studies involved the use of K^{42} . Radioactive potassium was obtained from the Atomic Energy Commission at Oak Ridge as irradiated units of potassium carbonate. The irradiated potassium carbonate as received was prepared as a 0.3 per cent solution, and applied to the leaves of plants. Detailed treatments of plants involving the use of isotopes will be described in each experiment. Tracer techniques were used for phosphorus and potassium studies. Autoradiograms, counts per unit of plant tissue, specific activity, and percentage of materials found in the various plant parts were used as indexes of absorption and translocation.

In most cases, the data were subjected to statistical analysis by using either the analysis of variance or student's "t" test.

EXPERIMENTAL

Experiment A. 1

Interrelation of Temperature and Photoperiod on the Response of Greenhouse Tomatoes to Foliar Applications of Sucrose

Objective

Preliminary experiments with applications of a ten per cent sucrose solution to the foliage of tomato plants failed to give a positive response. The plants were grown at 60°F. night temperature and an eight-hour photoperiod. The fact that sucrose is likely one of the first products of photosynthesis suggested the possibility that under favorable temperature-photoperiod relationships, it may be absorbed from foliage sprays and utilized in normal metabolic processes. The objective of this study was to interact temperature and photoperiod in an effort to determine the combinations that might give a response to sucrose sprays.

Materials and Methods

Michigan State Forcing tomatoes were planted in vermiculite.³ Four days after emergence, they were watered with a 0.78 per cent nutrient solution of an all-soluble fertilizer containing the equivalent of 10 per cent nitrogen, 52 per cent phosphorus pentoxide and 17 per cent potassium oxide.

³ An expanded mica purchased under the trade name of Terra-Lite.

Soon after the first two true leaves were formed, the plants were transplanted into four-inch clay pots containing a mixture of one-third muck and two-thirds loam soil. All plants were placed in the greenhouse at 60°F. night temperature for ten days allowing recovery from transplanting.

At the height of ten to twelve centimeters the control plants were dipped in water, while treated plants were dipped in a 10 per cent sucrose solution six times at five day intervals.

The short day (7 hrs.) was provided by the use of black curtains which were closed over the plants each day at 3:00 P.M. and opened at 8:00 A.M.. Fluorescent lighting was used to extend the photoperiod to fourteen hours.

Results

When the plants were grown at 60°F. night temperature, neither day-length nor sucrose sprays tended to cause a significant increase in dry weight. The results are summarized in Table I. Increasing the night temperature from 60°F. to 80°F. had little influence on dry weight production as long as the photoperiod remained at seven hours. When the photoperiod was increased to fourteen hours, 80°F. caused a 27 per cent increase in dry tissue over plants grown at 60°F. (Figure 1). Only when night temperature was 80°F. and day lengths held at seven hours did sucrose appear to cause an increase in dry weight. Under all other conditions, sucrose sprays apparently caused a small but consistent decrease in dry weight as compared with control plants at comparable temperatures and photoperiods.

Of special interest, as may be seen in Figure 2, is the fact that (except for a lighter green color in younger, or more rapidly growing regions) the sucrose treated plants when grown at 80°F. night temperature with short days, responded the same as plants grown at 80°F. night temperature with long days.

TABLE I

DRY WEIGHT OF GREENHOUSE TOMATO PLANTS IN RESPONSE TO
FOLIAGE APPLICATIONS OF SUCROSE WHEN INTERACTED WITH
TEMPERATURE AND PHOTOPERIOD

(Gms. dry wt./4 plants)

Environmental	Variables	Spray Treatments	
Night Temperature (°F.)	Day Length (hrs.)	Control - Water only	Sucrose - Six Applications
60	7	14.5	14.0
	14	15.4	15.1
80	7	15.0	23.0
	14	21.0	19.0



Figure 1. The response of tomato plants to applications of sucrose when grown at different photoperiods and temperatures.

Left to Right:

60°F. night temperature, seven hour day and no sucrose spray.

60°F. night temperature, seven hour day with sucrose sprays.

80°F. night temperature, seven hour day with sucrose sprays.

80°F. night temperature, 14 hour day and no sucrose spray.



Figure 2. Sucrose treated plants interacted with photoperiod and temperature.

Left: Plant grown at 80°F. night temperature with a seven hour day and sprayed with sucrose.

Right: Plant maintained at a night temperature of 80°F. with a 14 hour day and no sucrose.

Experiment A. 2

The Effect of Sucrose, Hormones and the "Missouri Method" of Pruning on the Yield of Greenhouse Tomatoes

Objective

Went and Carter (29) reported an increase in dry weight production by applying a 10 per cent solution of sucrose to the leaves of tomato plants when grown at a high temperature (80°F.) with short days (7 hours or less). This result was confirmed by the present investigations. In each of the cases above, yield (lbs. of fruit per plant) was used as an index to sucrose spray utilization. Although no growth increase was observed under conditions of low (60°F.) temperature with normal sunlight, it became desirable to know what effect sucrose sprays might have on the mobilization of carbohydrates by the fruit of tomatoes when grown under similar conditions. The objective was to determine if the yield of tomatoes grown in the late fall and winter under commercial greenhouse conditions in Michigan could be increased by applications of sucrose to the foliage. The factors most responsible for the derivation of this objective were the short days with low light intensities which prevail in Michigan during the major part of fall, winter and spring. It is apparent that light deficiencies limit photosynthetic activity and subsequent carbohydrate synthesis. It was theorized that attainment of the objective, the substitution of sucrose for light, might greatly offset the disadvantages of light deficiency.

For comparison, two other treatments were included. First, it was suggested (15) that when light is deficient, (duration or intensity) increased leaf surface might result in more efficient utilization of available light. For this purpose, the "Missouri Method" (15) of pruning was employed. Secondly, under climatic conditions common to Michigan during the fall, winter, and spring months, greenhouse grown tomatoes normally fail to set a good crop of fruit. Wittwer (32) found that a higher per cent of the flowers could be made to set fruit by applications of growth regulating chemicals. In order to increase the amount of fruit which, in turn, would decrease unit area of leaf surface per pound of fruit, a fruit setting chemical spray (alpha-orthochlorophenoxypropionic acid at forty parts per million) was included.

Methods and Materials

On July 3, 1949, ten varieties of tomatoes (Table III) were planted and subsequently grown in accordance with established commercial practices for producing plants for a fall crop in the greenhouse. On August 25, the plants were set in a highly productive greenhouse ground bed and grown at 60°F. night temperature.

Beginning September 15, the plants in treatments "C" and "E" (Table IV) were sprayed weekly with a 10 per cent sucrose solution. These spray applications were continued until the termination of harvest on January 5, 1950.

The open flowers of the plants in treatments "D" and "E" were sprayed weekly with a 40 parts per million solution (ppm) of alpha-ortho-chloro-

phenoxypropionic acid. Special care was taken in keeping the "hormone" spray off the foliage.

Treatment "B" consisted of the "Missouri Method" (15) of pruning. Usually, tomato pruning consists of removing the side branches from the main stem which arise in the leaf axis immediately below the flower clusters. Where the "Missouri Method" was employed, the side branch was removed not at its base, but rather, decapitated immediately above the second node, thus providing for two extra leaves below each flower cluster on the main stem. Treatment "A" consisted of the control plants which received no treatment.

Results

As indicated in Table II sucrose apparently caused an increase in yield over the control, but it was not sufficient to be statistically significant. This agrees with earlier experiments conducted at similar night temperatures. An increase was also noticed where the "Missouri Method" of pruning was used. Here again the differences were not of sufficient magnitude for statistical significance.

The use of fruit-setting chemicals (32) caused an increase in yield which was significant at the 1 per cent level. When sucrose sprays were combined with the "hormone" treatment no additionally favorable effect was obtained.

Ten varieties of tomatoes were used. Descriptions of these local greenhouse tomato selections are listed in Table III. Although no special emphasis was placed on observations of varietal interactions, the data are presented in Table IV.

TABLE II

THE EFFECTS OF SUCROSE, GROWTH REGULATORS AND THE "MISSOURI METHOD" OF PRUNING ON THE YIELD OF GREENHOUSE TOMATOES

Treatments	Treatment Averages Lbs. of Fruit/Plant		
Control - no treatment after setting in ground bed	3.81		
"Missouri Method" of pruning (extra leaves left on leaf axillary shoots)	4.10		
Ten per cent sucrose foliage spray weekly	4.06		
Hormone spray weekly on open flowers - ClPP - 40 ppm.	5.03**		
Sucrose and hormone sprays weekly	5.01		
Differences necessary for significance	<u>5 Per cent level</u>	<u>1 Per cent level</u>	
Treatments	0.63	0.79	

TABLE III

EXPLANATION OF VARIETAL SYMBOLS USED IN TABLE IV

Symbols	Varieties	Source
A	Michigan State Forcing X Waltham	John Holwerda Grand Rapids, Michigan
B	Eureka Hybrid #42	Roy Burghart Greenville, Michigan
C	WR3 Waltham 3rd. Generation	John Holwerda Grand Rapids, Michigan
D	Improved Baystate	John Holwerda Grand Rapids, Michigan
E	Michigan State Forcing	John Holwerda Grand Rapids, Michigan
F	Eureka Hybrid #32	Roy Burghart Greenville, Michigan
G	WR3 X Waltham #2	John Holwerda Grand Rapids, Michigan
H	Northern Hybrid	Roy Burghart Greenville, Michigan
I	Michigan State Forcing	Roy Burghart Greenville, Michigan
J	Spartan Hybrid	Roy Burghart Greenville, Michigan

TABLE IV

THE YIELD OF TEN VARIETIES OF GREENHOUSE TOMATOES AS AFFECTED
BY SUCROSE, "HORMONES" AND THE "MISSOURI METHOD" OF PRUNING.
Tomatoes (lbs./plant)

Varietal Selection*	A Control	B "Missouri Method" of Pruning	C Sucrose Sprays Weekly	D "Hormone" Spray Weekly	E Sucrose plus "Hormone" Spray Weekly	Means Variety Average
A	3.62	3.37	2.81	4.00	4.43	3.62
B	2.93	3.87	3.06	5.00	4.50	3.87
C	3.87	3.18	3.43	4.81	5.12	4.06
D	3.62	4.25	3.87	3.56	5.31	4.12
E	3.81	3.75	4.31	5.75	4.68	4.43
F	4.06	4.75	4.87	5.00	4.62	4.68
G	3.81	4.68	4.37	5.50	5.37	4.75
H	4.43	5.31	4.25	4.75	5.37	4.82
I	3.83	3.56	4.56	6.18	5.87	4.82
J	4.31	4.31	5.06	5.75	4.75	4.83
Means	3.83	4.10	4.06	5.03**	5.00	

Differences necessary for significance
Variety
Treatment
Variety X Treatment

5 Per cent level 1 Per cent level

1.42	1.92
.63	.79
.84	1.11

* See Table III.

Experiment B

The Effect of Foliar Applied Sucrose and Urea on the Growth and Development of Field Tomatoes 1949-50

Objective of Sucrose Sprays

A large percentage of the tomato transplants used in the north are shipped in from the southern states. Because of the seriousness of such problems as weather conditions immediately preceding the pulling of plants in the south, variations in temperature and humidity during transit, time required from pulling in the south to transplanting in the north, and weather conditions at the time plants are received and transplanted, this practice still has much to be desired. On the basis of present knowledge of plant growing, it is generally felt that the ability of the transplant to withstand the inevitable hardship coincident to transplanting is directly related to the carbohydrate reserves. The fact that sucrose has been shown to be the first free sugar formed in the leaf through photosynthesis (6) suggested that it may well be used in attempting to increase the carbohydrate content of the tomato transplant. For this purpose the leaves of tomato plants were dipped in a 10 per cent solution of sucrose and subsequently subjected to simulated commercial practices.

Objective of Urea Sprays

Earlier work with apple trees indicated that the answer to the problem of supplying nitrogen to crops having varying requirements during a given

reproductive cycle may probably be found in the use of nutritional sprays. Foliar feeding may also eliminate much of the loss of soil applied nutrients due to fixation and leaching. Like the apple tree, the tomato has a relatively high nitrogen requirement. The objective was to determine if the yield of field tomatoes could be influenced by foliage applications of urea.

Methods and Materials - 1949

On April 2, 1949 seed of John Baer and Rutgers tomatoes were planted in flats of vermiculite and placed in the 60°F. room in the greenhouse for germination. Two weeks later the seedlings were watered with a solution of an all-soluble fertilizer having an analysis of 10-52-17. At three weeks (April 23), the seedlings were transplanted from flats to four-inch clay pots containing two-thirds sandy loam and one-third muck. They were held at 60°F. night temperature until May 15, at which time they were randomly grouped for treatments in accordance with the experimental design.

Beginning on May 15, the plants in treatment "B" were sprayed with a 10 per cent solution of sucrose plus 0.1 per cent drefit. Repeated applications followed on May 17, 19, 22, 24, and 30. Treatment "C" was given its first and only sucrose treatment on May 30, the day that it (along with all other treatments) was set into the field.

On May 24, the potting soil was removed from the roots of treatments "D" and "E". The tops of the plants in treatment "D" were dipped in a 10 per cent sucrose solution, wrapped in paper toweling (ends open) which had been moistened in the sucrose solution, packed in orange crates and stored at 50°F. until May 30. Treatment "E" was treated the same as "D" except tap water instead of sucrose solution was used.

On May 30 the plants were set into a deep fertile sandy loam which had received ten tons per acre of manure the previous fall, followed by 1,000 pounds per acre of 3-12-12 in the spring. At transplanting time, the soil was relatively dry; therefore, water was applied during the operation. On the night of June 8, frost occurred, followed by a heavy rain on June 10.

On June 4, 7, 11 and 15, the plants in treatment III (Table VII) were sprayed with a 0.5 per cent urea solution, in the form of NuGreen, plus 0.1 per cent drest.

Results

The plants which were treated with sucrose prior to field transplanting appeared to have been thrown into a state of more rapid physiological activity as indicated by increased succulence and apparent growth during the storage period at 50°F. in complete darkness. All plants that were stored for 120 hours at 50°F. were injured by the frost which occurred on June 8. Those which received sucrose were damaged more severely. Plants which had not been treated with sucrose were in a "hardened" condition and consequently escaped severe damage by the frost. After being killed back sucrose treated plants recovered, producing new sprouts from the original central axis. These side shoots produced a crop, but remained considerably behind all other treatments. The effects of sucrose (as used in this experiment) on the early and total yield of field grown tomatoes are presented as averages of both varieties in Tables V and VI.

The effects of the urea sprays on the growth of the tomatoes were apparent very early in the season. On July 2, a count was taken of fruit that had set. The urea sprayed plants were considerably ahead at that time and remained so throughout the season. The early and total yield data for urea sprays are presented in Tables VII and VIII, respectively. These data clearly indicate that the urea sprays resulted in increases of both early and total yields. No difference in fruit quality due to treatment was noticed at any time.

TABLE V

EARLY YIELD OF FIELD TOMATOES AS AFFECTED BY SUCROSE SOLUTION
APPLIED TO THE FOLIAGE OF TRANSPLANTS (1949)
(lbs./12 plants)

Sucrose Treatments	Treatment Means
"A" Control	15.6
"B" Four weekly applications of sucrose	14.6**
"C" One application of sucrose at time of transplanting	15.9
"D" Moistened with 10% sucrose solution stored 5 days at 50°F. prior to transplanting	5.9
"E" Moistened with H ₂ O, stored 5 days at 50°F. prior to transplanting	8.7
Difference necessary for significance Sucrose Treatments	<u>5 per cent level</u> 5.06 <u>1 per cent level</u> 8.04

TABLE VI

TOTAL YIELD OF FIELD TOMATOES AS EFFECTED BY SUCROSE SOLUTION
APPLIED TO THE FOLIAGE OF TRANSPLANTS (1949)
(lbs./12 plants)

Sucrose Treatments	Treatment Means	
"A" Control	89.1	
"B" Four weekly applications of sucrose	94.7	
"C" One application of sucrose at time of transplanting	91.3	
"D" Moistened with 10% sucrose solution stored 5 days at 50°F. prior to transplanting	69.8	
"E" Moistened with H ₂ O, stored 5 days at 50°F. prior to transplanting	78.3	
	<u>5 per cent level</u>	<u>1 per cent level</u>
Differences necessary for significance Sucrose Treatments	19	32

TABLE VII

THE EFFECT OF UREA SPRAYS ON THE EARLY YIELD OF
FIELD TOMATOES (1949)
(lbs./5 plants)

Fertilizer Treatments	Variety		Treatment Means
	John Baer	Rutgers	
I. Control - No fertilizer after transplanting	12.00	4.10	8.05
II. 10-52-17 at time of transplanting	13.05	4.35	8.70
III. 10-52-17 as above 4 weekly applications of .75% urea spray	17.50	7.70	12.60*
Differences necessary for significance			
Fertilizer Treatment	5 per cent level		1 per cent level
	3.52		-----

TABLE VIII

THE EFFECT OF UREA SPRAYS ON THE TOTAL YIELD OF
FIELD TOMATOES (1949)
(lbs./5 plants)

Fertilizer Treatments	Treatment Means
I. Control - No fertilizer after transplanting	33.4
II. 10-52-17 at time of transplanting	33.6
III. 10-52-17 as above 4 weekly applications of .75% urea spray	38.9

None of the differences were significant.

Sucrose and Urea Sprays for Field Tomatoes (1950)

Further experiments were conducted in 1950 to check on certain questionable occurrences in connection with the 1949 work. In the first place, the late frost which occurred on June 8, 1949 apparently prevented the tomatoes from responding to sucrose as they probably would have under more favorable climatic conditions; secondly, it was desirable to determine if the favorable results derived from urea sprays could be repeated.

Methods and Materials

Seed of Victor and Rutgers tomatoes were sown on April 5, 12, 20, 28 and May 3, in vermiculite. They were grown to about 20 to 25 centimeters by following conventional procedures for tomatoes in the greenhouse and cold frame. The plantings were staggered, for the purpose of hedging against the possibility of complete loss because of late frosts. It also provided for the observation of tomato responses to sucrose and urea sprays under various climatic conditions within one growing season.

Five days before transplanting into the field the plants in treatments "B" and "C" (Table IX) were pulled from the four-inch pots and their roots washed free of soil. Treatment "C" plants were dipped in a 10 per cent sucrose solution, wrapped in paper toweling packed in orange crates. The plants in treatment "B" were dipped in water and packed in a similar manner. The two treatments were then stored for 120 hours under temperature conditions comparable to those of railway transit or truck shipments (50°F.). On May 20, 27, June 3, 13 and 23 respectively, the plants were removed from storage and transplanted along with the plants

TABLE IX

DESIGN OF EXPERIMENT B 1950*

Fertilizer Treatments	Sucrose and Storage Treatments		
	A	B	C
	Control - Neither stored nor spray- ed	Dipped in H ₂ O, stored 5 days at 50°F., prior to field trans- planting	Dipped in 10 per cent sucrose solu- tion stored 5 days at 50°F. prior to field transplanting.
I. Control - No nitrogen added			
II. Five field applications of 0.7 per cent urea sprays to the foliage.			
III. Five soil applications of urea comparable in quantity to Treatment II.		(Each cell contained 5 plants)	
IV. "Side dressed" with 150 pounds per acre of ammonium nitrate			
V. Treatments II and IV combined			

* This design was split to include Rutgers and Victor varieties of tomatoes, and was replicated 5 times.
The 5 replications were field transplanted on different dates (see text).

in treatment "A" which were not stored and consequently continued to grow normally during the 5-day storage period.

Beginning one week after transplanting, treatments II, III, and V (Table IX) were sprayed with a 0.7 per cent solution of urea. These sprays were repeated four times at seven day intervals. Treatments III and IV consisted of the application of ammonium nitrate to the soil near the tomato hills at the rate of 150 pounds per acre. This side dressing was performed seven to ten days following each transplanting. The field plot consisted of a Hillsdale sandy loam soil of very low fertility, to which 1000 pounds per acre of 0-20-20 was applied and disked in prior to the first transplanting.

Results

In terms of previous experiments, the results were negative. Data in Table X show that sucrose sprays not only failed to cause an increase in yield but also resulted in a decrease when compared with the control. Transplanting plants which had been previously sucrose treated, under different climatic conditions appeared to have little effect on their response. Generally the sucrose treated plants, when removed from storage, were more turgid, apparently more active physiologically, and could easily have been judged the better of the two treatments. Upon transplanting, however, the trend was almost immediately reversed. Under a wide range of weather conditions, the sucrose treated plants would soon become chlorotic progressing from the bottom upward followed by top necrosis. The remaining central axis would produce axillary branches which would finally develop a relatively healthy plant. The control plants retained

their foliage, were not affected by top necrosis, and recovered from transplanting in much less time. They remained ahead of the sucrose treated plants throughout the season.

In the case of urea sprays, the results were also disappointing. Although they caused a significant increase in early and total yields in 1949, Table XI indicates no such results in 1950. This applies not only to leaf applied nitrogen in the form of urea but also to ammonium nitrate applied to the soil. In each case (soil and leaf applied), nitrogen apparently caused an increase in vegetative growth, but this increase was not reflected in terms of yield.

Tables X and XI indicate that the yield of Victor tomatoes was consistently higher than that of Rutgers. Victor, being an early variety, produced mature fruits over a shorter period enabling it to develop a higher yield within the short season to which they were subjected. The Rutgers variety on the other hand is a heavy but late producer, and was not able to mature most of its fruit before the termination of favorable climatic conditions.

TABLE X

THE YIELD OF TWO VARIETIES OF TOMATOES AS AFFECTED BY
SUCROSE TREATMENTS
(lbs./5 plants)

Sucrose Treatments	Variety		Treatment Averages
	Victor	Rutger	
A Control - No sucrose and no storage	43	41	42
B Dipped in water and stored five days at 50°F.	54	32	43
C Dipped in a 10 per cent sucrose solution and stored as above.	52	26	39
Variety Averages	49**	33	

	<u>5 per cent level</u>	<u>1 per cent level</u>
Differences necessary for significance		
Variety	9.06	11.91
Treatment	No significant difference	

TABLE XI

THE EFFECT OF FERTILIZER TREATMENTS ON THE YIELD
OF TWO VARIETIES OF TOMATOES
(lbs. of fruit/5 plants)

Fertilizer Treatments	Variety		Treatment Averages
	Victor	Rutger	
I. Control - No nitrogen added after transplanting	45	32	38
II. Five weekly spray appli- cations of 0.7 per cent urea solution to foliage	48	34	41
III. Same as Treatment II except applied to soil	55	31	43
IV. "Side dressed" with 150 pounds of ammonium nitrate per acre	48	33	41
V. Treatments II and III combined	52	35	43
Variety Averages	49*	33	

	<u>5 per cent level</u>	<u>1 per cent level</u>
Difference necessary for significance		
Variety	9.06	11.91
Fertilizer Treatment	No significant difference	

Experiment C. 1

Urea Tolerance by Certain Vegetable Crops

The objective was to determine the maximum concentration of Urea that may be applied to the foliage of certain vegetable crops under greenhouse conditions without subsequent injury. Michigan State Forcing tomatoes, Utah #15 and Cornell #19 celery, cucumbers⁴, and Tender Green beans, were grown in sand culture at 60°F. (night temperature). When the seedlings were about ten centimeters tall, they were dipped four times at weekly intervals in Urea solutions varying from 0.25 to 10.0 per cent and each containing 0.1 per cent drefit. The relative tolerances of cucumbers, beans, tomatoes and celery to various spray concentrations of Urea are presented in Table XII.

In cases where injury is indicated as slight, marginal burning occurred only at the tip and extended not more than one-eighth inch into the blade of the young leaves. Medium injury indicated leaf tip burning over the entire plant. Severe injury designates that marginal burning occurred entirely around the leaf margins over the whole plant. Lethal injury indicates that the plants were killed by the Urea solution.

⁴ Selection of a white spine slicing cucumber. Seed generously furnished by: Yonker's Greenhouses, 1010 Twenty-Eighth Street, SE, Grand Rapids, Michigan.

TABLE XII

DEGREE OF LEAF INJURY ON CUCUMBERS, BEANS, TOMATOES AND CELERY
RESULTING FROM VARIOUS CONCENTRATIONS OF UREA SPRAYS

Per Cent Urea	Crop			
	Cucumber	Bean	Tomato	Celery
.25	None	None	None	None
.40	Slight	None to Slight	None	None
.50	Medium	Slight	Slight	None
.75	Severe	Medium	Medium	Slight
1.00	Severe	Severe	Severe	Medium
2.50	Severe	Severe	Severe	Severe
5.00	Lethal	Lethal	Lethal	Severe
10.00	Lethal	Lethal	Lethal	Lethal

Experiment C. 2

A Comparison of Leaf With Root Absorption of Nitrogen by Beans and Cucumbers

Objective

It has been clearly established that vegetable crops will utilize foliar applied nitrogen in growth processes. The extent to which nitrogenous sprays might replace soil application however, has not been determined. This experiment was conducted for that purpose.

Methods and Materials

On January 8, 1950 seed of cucumbers³ and tendergreen beans were planted in five-inch pots containing a medium composed of one-half washed sand and one-half coarse vermiculite. After germination, each pot was watered with one hundred milliliters of a nutrient solution containing forty-two grams of monopotassium phosphate per gallon of water. The plants were then left to grow until nitrogen deficiency symptoms were clearly evident. The plants were treated February 4. Treatment "A" consisted of the control plants which received no nitrogen. The plants in treatment "B" were dipped twice weekly for four consecutive weeks in a 0.5 per cent urea solution. Plants in treatment "C" were soil watered once with one hundred milliliters of a nutrient solution composed of twenty-eight grams of diammonium phosphate per gallon of water. Because of the short duration of the experiment and the type of medium used, no attention was given the application of minor elements.



Figure 3. The relative growth of bean plants receiving leaf and soil nitrogen. Left to right. No nitrogen added, leaf nitrogen, and soil nitrogen.

Results

Resulting fresh weights for the two crops are presented in Table XIII. Plants receiving nitrogen on the soil and on the foliage began to show evidence of utilization by the fifth day after the first treatment. By ten days after the initial treatment the plants which received nitrogen on the soil began to show more rapid growth and development than was apparent from foliar treatment. By the date of termination (April 23), the soil treatment was definitely superior (Figures 3 and 4). Control plants which received no nitrogen made practically no growth after the first three weeks following germination and were becoming quite necrotic at the end of the experiment.



Figure 4. Comparative response of cucumbers to applications of soil and leaf nitrogen. Left to right. No nitrogen, leaf nitrogen, soil nitrogen, and leaf + soil nitrogen.

TABLE XIII

THE EFFECT OF SOIL AND LEAF APPLIED NITROGEN ON THE FRESH
WEIGHT OF BEANS AND CUCUMBERS
(Fresh wt. gms./3 plants)

Nitrogen Treatments		B-9592 Beans	Prolific Cucumbers
"A"	Control - no nitrogen added	12	3
"B"	8 foliage applications of 0.5 per cent urea	25	14
"C"	One soil application of di-ammonium phosphate	61	45



Figure 5. Comparative growth response of tomato plants to applications of nitrogen to the leaves and the soil. Left to right. No nitrogen, leaf nitrogen, soil nitrogen.

Experiment C. 3

The Effect of Temperature on the Absorption and Utilization of Foliar Applied Nitrogen by Greenhouse Celery

Objective

Some knowledge of the effects of environment on the utilization by plants of foliar sprays of urea might be most advantageous. The universality of the importance of temperature relations to plant responses, forced its consideration. Consequently, a study was designed to determine the response of celery to foliage application of nitrogen under a wide range of night temperatures. A preliminary observation was also made on the use of "Geon 600"⁵ as a sticker in connection with urea sprays on celery.

Methods and Materials

Seed of Cornell #19 and Utah #15 celery were planted in January in flats containing one part sand and two parts muck. The flats were placed in the 70°F. room and subsequently managed according to established plant growing practices for this crop. On March 25, the seedlings were transplanted into six-inch pots containing one part vermiculite and two parts washed sand. On April 4, the plants were then placed at 40, 50, 60, and 70°F. night temperatures as designated in Table XIV. Foliage sprays consisting of 0.75 per cent solutions of Urea were started on April 4 and continued bi-weekly for one month. One-tenth of one per cent drefit was

⁵ Geon 600 - A latex preparation furnished by the B. F. Goodrich Chemical Co., Cleveland, 15, Ohio.

added as a wetting agent except when "Geon 600" was used. In this case, a 5 per cent solution of "Geon 600" containing 0.75 per cent Urea was applied at the time of other spray treatments; (Table XIV). The plants in treatments "D" and "E" were given a soil application of one hundred milliliters of a 1 per cent solution of di-ammonium phosphate which was considered an adequate amount of nitrogen for the four-week period.

Results

The data in Table XIV show that celery plants which received no nitrogen made very slow growth. Urea sprayed plants were significantly larger than plants which received no nitrogen. It may also be noticed, that plants receiving soil nitrogen were significantly larger than the urea sprayed plants. The greatest amount of growth occurred in the plants which received both soil and leaf nitrogen. Urea sprayed solutions containing "Geon 600" (latex) generally caused more growth than when drefit was used instead. However, as noted in Table XV, where the data for all temperatures are combined, the difference was not significant.

Various night temperatures resulted in marked differences in the response of celery to the fertilizer treatments. This was especially true when comparing plants grown at 40°F. and 70°F., with 50°F. and 60°F.

The data in Table XIV indicate that there was no consistent difference in the celery grown at 50°F. and 60°F. The greatest responses to foliar applications of nitrogen as compared with soil application were at the 40 and 50°F. temperatures.

According to the data in Table XV, Cornell #19 and Utah #15 varieties of celery responded similarly to the various fertilizer treatments. The data in Table XIV indicate that the same may be said of varietal interaction with night temperatures.

TABLE XIV

THE DRY WEIGHT OF TWO VARIETIES OF GREENHOUSE GROWN CELERY AS AFFECTED
BY METHOD OF APPLICATION OF NITROGEN AND NIGHT TEMPERATURE
(gms. dry wt./4 plants)

Nitrogen Treatments	Cornell #19				Utah #15			
	40°F.	50°F.	60°F.	70°F.	40°F.	50°F.	60°F.	70°F.
A Control - no nitrogen added	1.0	1.0	0.8	2.0	0.6	0.4	1.6	2.0
B 8 foliar applications of .75 per cent urea plus 10 per cent latex (Geon 600)	3.2	5.0	4.0	5.2	4.0	3.1	4.0	4.2
C 8 foliar applications of .75 per cent urea plus 0.1 per cent drefit	2.2	3.5	4.2	4.3	3.4	3.0	3.8	3.0
D 1 gram of di-ammonium phosphate on soil	5.5	8.1	8.3	8.4	4.1	8.3	8.0	10.0
E Treatments C and D combined	6.0	10.0	9.5	10.3	6.8	10.0	6.2	10.7

TABLE XV

THE EFFECT OF SOIL AND LEAF APPLIED NITROGEN ON THE DRY WEIGHT
OF CORNELL #19 AND UTAH#15 CELERY GROWN IN THE GREENHOUSE
(Gms. dry wt./4 plants)

Fertilizer Treatments	Cornell #19	Utah #15	Treatment Averages
A Control - no nitrogen added	4.8	4.6	4.7
B 8 foliar applications of 0.75 per cent urea 5 per cent latex	17.4	15.3	16.3**
C 8 foliar applications of 0.75 per cent urea 0.1 per cent dreft	14.2	13.2	13.7
D 100 ml. of 1 per cent solution of di-ammonium phosphate on soil	30.3	30.4	30.3**
E Treatments 3 and 4 combined	35.8	33.7	34.7
Variety Averages	20.5	19.2	

	<u>5 per cent level</u>	<u>1 per cent level</u>
Differences necessary for significance		
Treatment	5.1	8.9
Variety	No significant difference	

TABLE XVI

THE DRY WEIGHTS OF GREENHOUSE-GROWN CELERY AS AFFECTED BY METHOD OF
APPLICATION OF NITROGEN AND NIGHT TEMPERATURE
(gms. dry wt./4 plants)

Nitrogen Treatments	Night Temperature-Degrees Fahrenheit				Treatment Averages
	40°	50°	60°	70°	
A Control - no nitrogen added	1.6	1.4	2.4	4.0	2.3
B 8 foliar applications of .75 per cent urea plus 5 per cent latex (Geon 600)	7.2	8.1	8.0	9.4	8.2**
C 8 foliar applications of .75 per cent urea plus 0.1 per cent drefit	5.6	6.5	8.0	7.3	6.8
D 1 gram of di-ammonium phosphate to soil	9.6	16.4	16.3	18.4	15.2**
E Treatments C and D combined	12.8	20.0	15.7	21.0	17.4
Treatment Averages	7.3	10.5**	10.1	12.0*	

Differences necessary for significance	5 per cent level	1 per cent level
	2.6	4.5
Nitrogen Treatments		
Temperature	1.8	3.2

Experiment C. 4

The Effect of Nitrogen Sprays on the Yield of Early Field Celery

Objectives

In an earlier greenhouse experiment, urea sprays were applied with favorable results to two varieties of celery growing in sand culture at four different night temperatures (40°, 50°, 60°, and 70°F.). Although, percentage-wise, the greatest responses of both varieties to urea sprays occurred at 50°F. to 60°F., considerable increase in weight was also noticed when plants were grown at either 40°F. or 70°F.

In Michigan, early summer celery is transplanted into cold muck soil during the months of April and May. Under these conditions, even in the presence of a tremendous supply of reserve organic nitrogen, it is assumed that microbial activity is practically nil and consequently available nitrogen is quite low, if present at all. Even if soil nitrogen is available, it may not be efficiently used as long as the soil temperatures remain relatively low. It has been reported (20) that as soil temperatures decrease below the optimum for a given plant, the rate of soil moisture uptake is decreased proportionately. Although the absorption of soil nitrogen (17) may not depend upon the absorption of soil moisture, they are closely related and are expected to move together in cases where both are present.

The fact that urea sprays gave positive results at 40°F. in the greenhouse suggested the possibility that a similar treatment could influence the growth of early celery. On this premise, an experiment was

designed and conducted to determine the effect of foliage sprays of urea on the yield of early field celery.

Methods and Materials

Seeds of two varieties (Cornell #19 and Utah #15) of celery were planted in flats and the seedlings subsequently handled according to established commercial practices. On May 23, 1950, the plants were set in the field. The field plot was a well drained, highly productive muck which was fertilized just prior to setting the plants with 150 pounds per acre of sodium chloride, five pounds per acre of borax, and 1,000 pounds per acre of 0-20-20.

On May 30, one week after transplanting, the plants in treatments "B", "C", and "E" (Table XVII) were sprayed with a 1 per cent solution of urea. These treatments were repeated on June 2, 7, 15, and July 6. On June 7, treatments "D" and "E" were side dressed with 150 pounds per acre of ammonium nitrate. Environmental conditions were favorable throughout the season. Adequate soil moisture was maintained by means of a portable irrigation system, and a controlled water table which fluctuated between 24 and 28 inches.

Results

The data in Table XVII indicate that urea foliage sprays significantly increased the growth of early field celery. This increase, derived from foliar applications of urea, was greater than that resulting when the same amount of urea was applied to the soil. Soil application of the ammonium nitrate produced increased growth in the plants as compared to

those which received no additional nitrogenous fertilization after transplanting: however, this increase was not as great as that which was caused by six applications of 1 per cent urea spray on the foliage. The highest yield was derived from a combination of urea to the foliage and ammonium nitrate application to the soil. Although plants receiving ammonium nitrate in soil application yielded significantly higher than plants which received no additional nitrogen after transplanting, an additional increase was super-imposed when the soil treated plants were subsequently foliar sprayed with urea.

Early in the season (while the nights remained cool), the check plants which were neither side dressed with ammonium nitrate nor sprayed with urea, became quite chlorotic and made very slow growth. As the season progressed with higher night temperatures, nitrates apparently became available, the plants recovered, and began to grow normally. They later produced a good yield of marketable stalks, but production was less than from plants which had been given an early start with urea sprays.

There was apparently no difference in the response of the two varieties to fertilizer treatments. Although the varieties represented distinct celery types (green and golden), trends in growth response to foliar applied nitrogen were similar. The data presented in Table XVIII serve to illustrate the patterns of varietal response to soil and foliage applications of nitrogenous fertilizers.

TABLE XVII

THE EFFECT OF SOIL AND LEAF NITROGEN ON THE YIELD
OF EARLY FIELD CELERY

Treatments	Yield of Trimmed Celery (lbs./5 ft. plots)
A Control - no fertilizer after transplanting	19.3
B Six foliar applications of urea (1.0%)	24.8**
C Six applications of 1.0 per cent of urea to the soil	20.9
D Soil application of ammonium nitrate (150 lbs./acre)	22.6*
E Treatment "B" plus "D"	25.6**
<u>5 per cent level</u> <u>1 per cent level</u>	
Differences necessary for significance	
Treatment	2.19 3.62

TABLE XVIII

THE YIELD OF TWO VARIETIES OF CELERY AS AFFECTED BY
SOIL AND FOLIAR APPLIED NITROGEN

Fertilizer Treatments	Yield of Trimmed Celery (lbs./5 ft. plots)		Treatment Means
	Cornell #19	Utah #15	
A Control - no fertilizer after transplanting	18.50	20.00	19.3
B Six foliar applications of urea (1.0%)	23.25	26.25	24.8**
C Six applications of 1.0 per cent of urea to the soil	20.00	21.75	20.9
D Soil application of ammonium nitrate (150 lbs./ acre)	21.00	24.25	22.6
E Treatment "B" plus "D"	23.50	27.75	25.6*
Variety Averages	21.25	24.00	

	<u>5 per cent level</u>	<u>1 per cent level</u>
Differences necessary for significance		
Variety	1.39	2.29
Treatment	2.19	3.62

Experiment D.

The Effect of Soluble Fertilizer Sprays on the Yield of Greenhouse Tomatoes

Objective

The possibilities of foliar feeding as a means of supplying the major mineral nutrients to plants has provided a challenge to industrial chemists to produce concentrated, all soluble, relatively non-injurious carriers of one or more of the essential nutrients desired for foliar applications. Industry has responded to this challenge; consequently there are literally dozens of soluble plant food concentrates on the market all highly recommended by their respective producers. Except for the manufacturer's "cure-all salesmanship", practically nothing is known of the actual performance of these fertilizers. It was decided to select a few of these materials and, on the basis of the manufacturers' recommendations, give them a fair trial for foliar feeding. Hence, the objective was to determine the effect of certain all-soluble fertilizer materials on the yield of greenhouse tomatoes when applied to leaves during the critical period of fruit setting.

Methods and Materials

Four replications of each treatment were set up on a highly productive commercial greenhouse soil in the Grand Rapids area devoted to tomato production. The ground beds of replications one and two had been supplied with an abundant amount of legume hay. After turning the hay into the

soil, the ground bed was steam sterilized preceeding transplanting. Replications three and four were treated similarly except they were not sterilized. All replications received, 0-20-20 at the rate of 500 pounds per acre under the rows when the plants were set.

The Spartan Hybrid variety of greenhouse forcing tomato was used. In replications one and two they were about four feet, six inches in height with 3 to 4 fruit clusters at the beginning of this study. In replications three and four, they were about three feet tall with 2 to 3 fruit clusters on each plant.

The fertilizer materials varied very widely in composition and concentration. Consequently, the producer's recommendations were followed. Table XIX lists the fertilizer materials studied by trade name, along with pertinent information on each. A three gallon hand sprayer was used to apply these materials. They were made up in two gallon lots according to the recommendations listed in Table XIX.

The experiment was set up as indicated in Table XX. The first applications were made May 5, 1950. Others followed on May 11, 17 and 26. In order to facilitate wetting, 0.1 per cent dreft was added to all spray solutions. In applying the spray, a special effort was made to wet both sides (upper and lower) of the tomato leaves. The soil between the rows of plants was mulched with a four-inch layer of straw. No further effort was made to keep excess spray material from dripping on the soil.

Results

By the time of the third spray application, no visible positive effect of the first two applications was evident. Very slight injury as

indicated by marginal leaf burning was evident on treatments where "Nu-Green", "Take Hold", and "Armour All-Soluble" were used. This slight injury to the foliage did not appear to effect the over-all performance of the plants. No injury was noted with other treatments.

The yield data are presented in Table XX. By comparing replications one and two with three and four, a significant difference in performance is observed.

In a comparison of the yield resulting from the application of each of the fertilizer materials, it is of special interest to note the lack of correlation between fertilizer analysis and production responses. Although some of the materials contained minor elements and vitamins, there was no significant difference in growth due to their presence. In fact, the greatest response came from "NuGreen", a nitrogen carrier, its only other nutrient contribution being traces of magnesium.

TABLE XIX

DESCRIPTION OF ALL-SOLUBLE FERTILIZER MATERIALS

Trade Names	Analysis N-P-K	Other Nutritional Contributions	Foliage Recommendation lbs./100 gal. H ₂ O
Armours	15-52-9	None	6 lbs.
Hy Gro	13-26-13	None	5 lbs.
Kap Co	15-30-15	Mg. Fe. S. Cu. B.	3 lbs.
Nachurs	5-10-5	Trace elements	1 qt.
NuGreen	44-0-0	Traces of Magnesium	6 lbs.
Rapid Gro	23-21-17	Vit. B ₁ and B ₂	6 lbs.
Take Hold	11-52-17-	None	6 lbs.
V.H.P.F. "Vip"	5-25-15	None	6 lbs.

THE EFFECT OF SOLUBLE FERTILIZER SPRAYS AND STEAM STERILIZATION
ON THE YIELD OF GREENHOUSE TOMATOES

Fertilizer Materials	Replications				Treatment Averages (lbs./ 10 plants)
	Soil Sterilized		No Sterilization		
	I	II	III	IV	
Control	101	83	49	48	70.0
Take Hold	95	77	44	67	70.0
Hy Gro	76	82	66	74	75.0
Nachurs	103	80	52	73	77.0
Rapid Gro	98	88	51	72	77.0
Armours	91	90	67	64	78.0
V.H.P.F.	98	102	58	62	80.0
Kap Co	100	94	69	66	82.2*
NuGreen	105	89	73	64	83.0*
Replication Averages	96.3	87.5	58.8	65.6	

		<u>5 per cent level</u>	<u>1 per cent level</u>
Differences necessary for significance			
Fertilizers		12.00	
Replications		8.42	13.83

TABLE XXI

RELATION OF FERTILIZER ANALYSIS OF NUTRITIONAL SPRAYS
TO RESPONSE BY GREENHOUSE TOMATOES

Fertilizers by Trade Names	N-P-K Analysis	Treatment Averages (lbs. fruit/plant)
Control	0 - 0 - 0	7.0
Take Hold	10-52-17	7.0
Hy Gro	13-26-13	7.5
Nachurs	5-10- 5	7.7
Rapid Gro	23-21-17	7.7
Armours	15-52- 9	7.8
V.H.P.F.	6-25-15	8.0
Kap Co	15-30-15	8.2*
NuGreen	44-0-0	8.3*

	<u>5 per cent level</u>	<u>1 per cent level</u>
Differences necessary for significance		
Fertilizers	1.2	_____

Experiment E. 1

The Absorption and Translocation of Foliar Applied Radioactive Phosphorus and Potassium by Bean and Squash Seedlings

Objective

That certain vegetable crops could utilize foliar applied nitrogen seemed fairly well established. Because of the possible advantages of nutritional sprays, and the relative importance of phosphorus and potassium fertilization in vegetable crop production, it was considered desirable to include these two materials in further "leaf feeding" studies utilizing radioactive isotopes. Unfortunately no radioactive isotopes of sufficient half-life of the nutrient nitrogen are available, and facilities were not available for stable isotope analysis. The objectives of the initial experiment with phosphorus and potassium were to determine the rate and extent of absorption and translocation from the leaves as indicated by radioactive isotopes.

Methods and Materials

Tender Green beans and Summer Prolific Straight Neck squash seeds were planted in four-inch pots containing washed sand. Because of the short duration of the experiment, and the large food reserves in the seed of these crops, no nutrients were added to the media. When the plants were about ten centimeters tall, one of the paired primary leaves of the bean and the first primary leaf of the squash were dipped in a 0.3 per cent solution of ortho-phosphoric acid containing radio active

phosphorus (P^{32}) at a concentration of one microcurie per milliliter. A second group of bean and squash seedlings were similarly dipped in a 0.3 per cent solution of potassium carbonate, containing radioactive potassium (K^{42}) of unknown specific activity. The plants were temporarily left in a horizontal position (as shown with a potato plant in Figure 9) to dry in order to prevent any solution from dripping on the soil. Beginning six hours after dipping, samples of four plants of each kind and treatment were harvested and separated into two parts; the first being the leaf treated and the second, the remainder of the plant including foliage, stem, and roots. Subsequent harvests followed at 18, 36, 72 and 172 hours after the plants were dipped. After harvest, all treatments were placed in number two crucibles and dried at 80°F. To all crucibles containing radioactive phosphorus samples, three milliliters of 10 per cent magnesium nitrate solution was added. This was to provide excess magnesium needed in converting organic phosphorus to magnesium pyro-phosphate which was not volatile at the temperatures used in the experiment. All crucibles containing plant material were then held in a muffle furnace for six hours at 650°C. for ashing.

Scaler⁶ readings in counts per minute were taken directly over the crucibles containing the ashed plant samples. Total counts on the leaves treated at the beginning of the experiment were taken as 100 per cent of the material applied. Subsequent readings on other plant parts with the progression of time were compared with this value in determining percentage of absorption and translocation from the leaves treated (Figure 7).

⁶ Tracer Lab Autoscaler: Code SC-IB Manufactured by Tracerlab Inc., 221 North LaSalle St., Chicago, Ill.

At the same time that plants were harvested for ashing, a separate group was harvested and prepared for autoradiograms in accordance with methods outlined by Wittwer and Lundahl (33).

Preparation of autoradiograms involved essentially the following procedures:

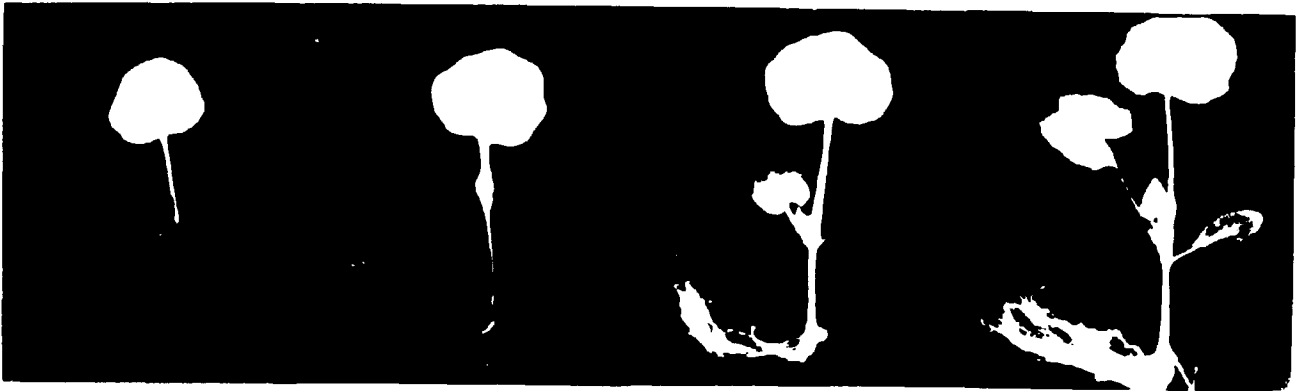
1. Washing seedling roots free of sand with tap water.
2. Removing excess or residual phosphorus and potassium from the leaves treated by momentarily dipping in a series of beakers containing a 0.3 per cent solution of ortho-phosphoric acid, and finally in a beaker of distilled water.
3. Placing plant between two sheets of botanical specimen paper and drying under pressure with infra-red heat lamps.
4. Removing botanical specimen paper from both sides of the plant and replacing it with a sheet of pliofilm on one side, and a new sheet of absorbent paper on the other.
5. Pressing plio-film side to 8x10 inch, No-screen Kodak X-ray film with steel plates and leaving in the dark (photographic) room five to seven days for exposure.
6. The films were then processed by using X-ray developer and fixative.

Results

Figures 7a and 7b indicate that radioactive phosphorus and potassium, when applied to the foliage of beans and squash, begin to move to other parts of the plant almost immediately. Phosphorus (Figure 7a) seems to

Figure 6A. Autoradiograms of bean and squash plants following treatment of one of the primary leaves of the bean and primary leaf of the squash with radioactive phosphorus (P^{32}). Plants were harvested (reading from left to right) at 6, 24, 48 and 72 hours.

Figure 6B. Autoradiograms of bean and squash plants following treatment of one of the primary leaves of the bean and primary leaf of the squash with radioactive potassium (K^{42}). Plants were harvested (reading from left to right) at 6, 24, 48 and 72 hours.



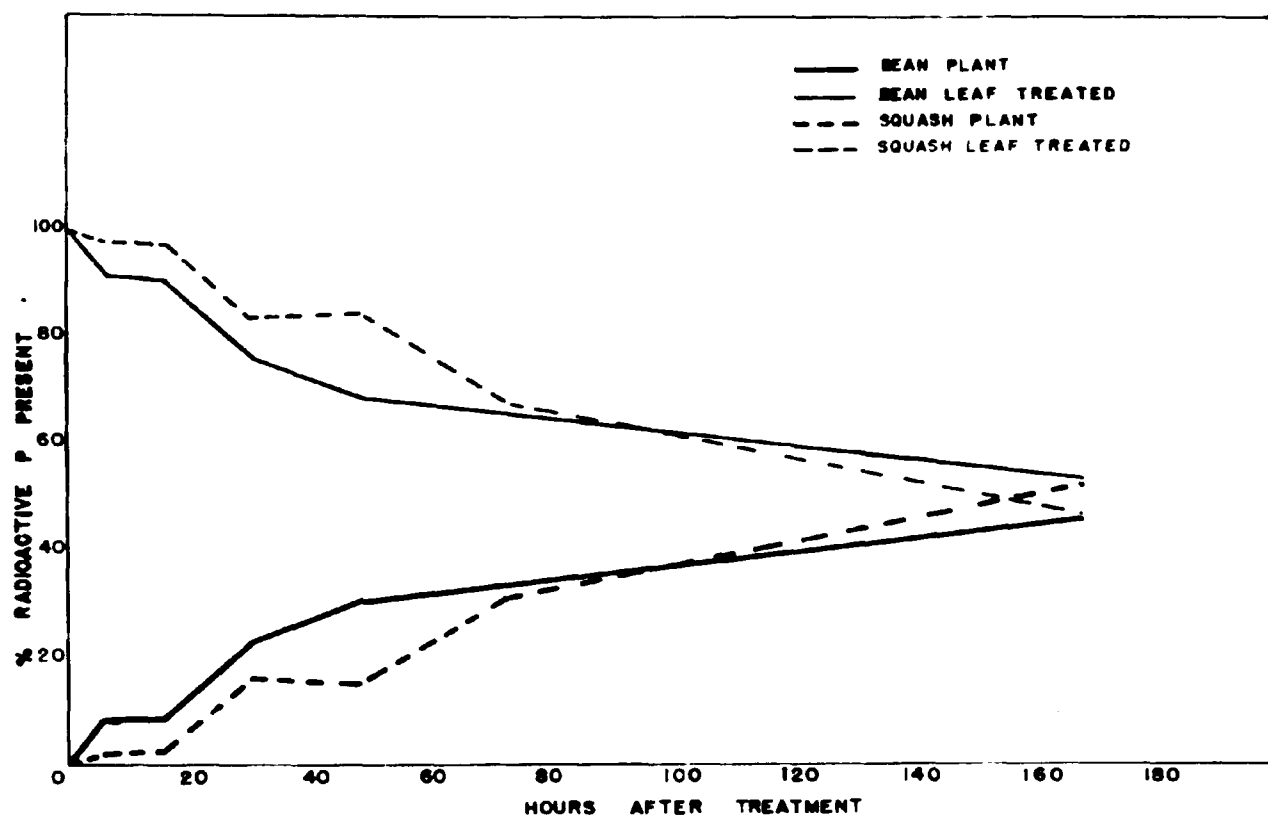
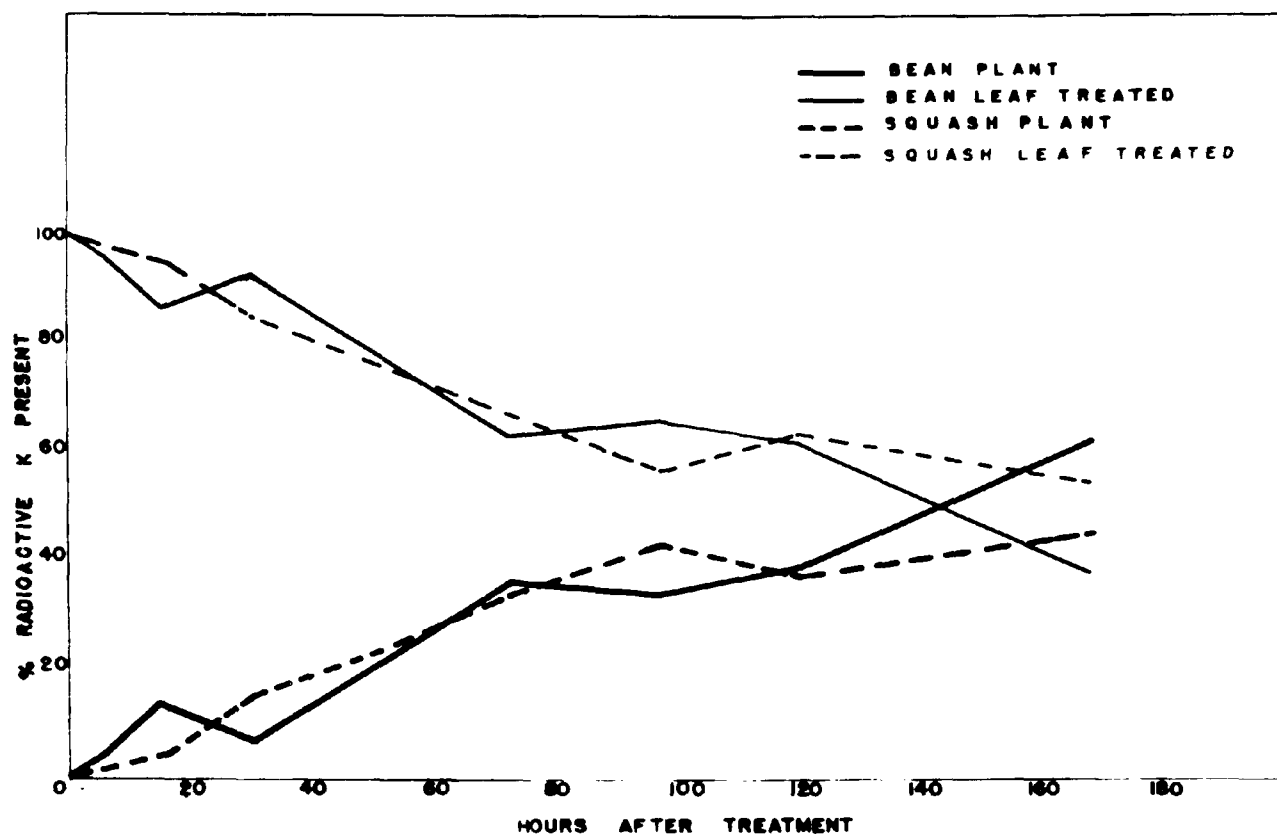
move more rapidly during the first 48 hours after application followed by a continuous movement out of the leaf treated but at a decreasing rate. The pattern of movement of potassium was practically a straight line function (Figure 7b). Within the limit of this experiment, the rate of movement of potassium was less affected by the amount present on the leaf than by length of reacting time.

An interesting sidelight as indicated in the autoradiograms was the pattern of phosphorus and potassium accumulation in bean and squash seedlings. Figure 6a indicates that phosphorus accumulated first in the meristematic regions (root tips, apex, etc.). After these regions were well supplied, phosphorus then tended to move to all parts of the plant.

Potassium did not tend to move to the meristem in preference to older tissue, but rather was more equally distributed through the entire plant.

Figure 7A. Translocation of foliar applied radioactive potassium from leaf treated of bean and squash plants to the remainder of the plant at various time intervals subsequent to treatment.

Figure 7B. Translocation of foliar applied radioactive phosphorus from leaf treated in bean and squash plants to the remainder of the plant at various time intervals subsequent to treatment.



Experiment E. 2.

The Mobilization of Radioactive Phosphorus by the Fruits of Greenhouse Tomatoes from Leaf and Soil Application as Affected by Temperature

Objective

As indicated in the autoradiograms of bean and squash seedlings, radioactive phosphorus moved very rapidly to meristematic tissue when applied to the foliage. In this case, night temperatures for growing the plants were maintained at 60°F. Under field conditions, tomatoes are subjected to a wide range of night temperatures, varying from as low as 35°F. to 40°F. early in the season, to as high as 80°F. to 90°F. by mid-summer. Under these varying temperatures, it might be expected that the intensities of physiological activities may vary greatly. The extent to which these variations influence the mobilization of phosphorus from soil as compared with leaf application may have considerable practical significance. Therefore, an experiment was designed with two objectives in view. First, to determine the rate and efficiency of leaf absorption and translocation of phosphorus as affected by various temperatures; and secondly, to compare the rate of absorption and translocation of radioactive phosphorus from soil and leaf application. The relative amounts of radioactive phosphorus in comparable fruits harvested from plants subjected to the different treatments was used as an index of the efficiency of foliar versus root absorption at the varying temperatures.

Methods and Materials

Plants of Michigan State Forcing variety of tomatoes were grown as usual from seed sown in vermiculite. After three weeks, the seedlings were pricked off into eight-inch pots containing a fertile sandy loam soil. After transplanting, the plants were watered with a 0.78 per cent solution of equal quantities by weight of monopotassium and di-ammonium phosphates, and placed in the 60°F. room. To induce profuse flowering, especially on the first clusters, they were kept dry (often to the point of incipient wilting). This experiment was conducted in mid-winter in the greenhouse. Under these conditions, usually, a very poor natural fruit-set results. In order to overcome the unfavorable effects of environment on fruit setting, the open flowers were sprayed with forty parts per million of alpha-ortho-chlorophenoxypropionic acid solution. This resulted in a relatively uniform fruit set on all plants. When these fruits averaged one centimeter in diameter an equal number of plants were moved to greenhouse units maintained at 45, 60 and 75°F. night temperatures. To permit the plants to come to equilibrium with the respective room temperature to which they were to be exposed, they were retained for 24 hours before the radioactive phosphorus treatments were administered. At that time the plants receiving foliage applications were dipped momentarily in a 0.3 per cent solution of ortho-phosphoric acid assaying one micro-curie per milliliter of radioactive phosphorus. The dipping procedure followed the pattern shown with potatoes in Figures 8, 9 and 10.

The plants receiving the soil applications were watered with fifty milliliters of 0.3 per cent ortho-phosphoric acid containing radioactive



Figure 6. Method used in dipping plants in radioactive solutions.



Figure 9. Potato plant placed in horizontal position after dipping to prevent excess solution from falling on the soil.



Figure 10. Potato plant placed in pan and watered from below to avoid washing radioactive materials from the leaves onto the soil.

phosphorus at a concentration of 0.1 micro-curie per milliliter. Twenty-four and 48 hours after the foliar and soil applications of radioactive phosphorus were made, fruits were harvested from each of four plants of each treatment at each temperature. After drying at 80°C. the fruits were placed in covered crucibles, saturated with 0.5 normal magnesium nitrate and ashed at 650°C. for six hours. After cooling the ash was dissolved in ten milliliters of 10 per cent hydrochloric acid, then brought up to 25 milliliter volume with distilled water. An aliquot of one milliliter from each sample was placed in a one-fourth ounce sample box and evaporated at 60°C. These boxes were then placed under a Geiger-Muller tube for radioactive analysis as recorded by a Tracerlab auto scaler. These data were converted first to counts per minute for the aliquot, then counts per minute per total plant sample, and finally counts per minute per milligram of the original fruit sample.

Results

The data for this experiment are presented in Table XXII. They show very clearly that temperature had little if any influence on the mobilization of leaf applied phosphorus by the tomato fruits. At 48 hours after treatment, the amount of radioactive phosphorus which moved from the leaves into the fruit was practically the same at all temperatures used. The 24 hour sample at 45°F. was low. This was probably because of the irregularities in sizes of fruits in the sample. A similar condition characterizes the 48 hour sample harvested from plants grown at 45°F. and in which the phosphorus was applied to the soil. The pattern of move-

ment of phosphorus into the fruit from soil applications as affected by various temperatures is apparently different from that of foliar applied phosphorus. On the basis of these data, as the temperature is decreased the relative amount of phosphorus absorbed from the soil, but not the leaves, is decreased. It was particularly interesting to note that only at the high (75°F.) temperature did soil absorption exceed that from the leaves.

TABLE XXII

INFLUENCE OF NIGHT TEMPERATURES ON THE MOVEMENT
OF RADIOACTIVE PHOSPHORUS INTO THE TOMATO FRUITS
FROM SOIL AND LEAF APPLICATIONS

Night Tempera- tures °F.	Hours After Treatment	Soil Application (counts/milligram dry tissue)	Foliage Application
75°	24	23.60	21.50
	48	60.59	54.27
60°	24	11.82	29.05
	48	14.30	51.0
45°	24	8.90	11.97
	48	3.33	56.06

DISCUSSION

The newness of the concept that the major nutrient elements (nitrogen, phosphorus, and potassium) can be supplied to vegetable crops through the foliage poses questions as to the advisability or advantages to be derived therefrom. Advantages of such a method of crop fertilization are not difficult to enumerate when one considers the established disadvantages of conventional soil application methods. When some nutrients are applied to the soil, they are subjected to chemical, physical, and biological fixation, all of which result in decreased efficiency of plant utilization. Some soil applied nutrients are also subjected to a high rate of loss by leaching. Jones and Rogers (19) suggested that soil fixation and leaching losses may be eliminated by the use of foliage sprays. Further, foliage sprays provide a direct and immediate means of supplying nutrients to growing plants and accomplish it with much less material. According to Spencer and Stewart (26) inorganic phosphate may be unavailable resulting from chemical fixation and lack of sufficient penetration into the root zone. Pink, Sherman, and Allison (22) reported that colloidal as well as microbial activity may play a roll in the fixation of phosphorus.

Mechanism of Foliar Absorption and Translocation

The results of the experiments herein reported involving foliar application of nutrients to vegetable crops reveal some remarkable facts. Among these is the rate at which certain materials are absorbed by the

leaves and translocated to other organs. This is particularly true of phosphorus and potassium and may possibly apply to nitrogen as well. Although, under certain conditions, sucrose is likely to be absorbed and utilized by certain vegetable crops when applied to the foliage, experiments discussed in this thesis did not provide for rate determinations.

The rapidity with which certain materials are absorbed by the leaves of some crops raises the question of the mechanism involved. For many years classical anatomical concepts led plant physiologists to feel that generally, plant leaves are covered by a continuous cuticle which is practically impermeable to water. Under these conditions one would not expect solutes to readily pass into the plant via the leaf. Today, plant anatomists are not so sure that the surface of leaves are completely covered with cutinized layers. Recent work clearly indicates that the "authorities" are divided on the subject. As late as 1949, Hayward (14) described the cuticle as a protective non-cellular membrane, which forms an impervious layer except where there are stomata. Eames and MacDaniels (8) agreed with Hayward on the "Continuous Cuticle" theory. They claimed that the only breaks in the continuity of the cuticle are at the openings of the stomata and the lenticels. In a statement concerning the origin and function of the cuticle, they suggested that the cuticle is a secretion of the epidermal cells which, in apparently a liquid or semi-liquid form, is passed through the outer wall forming a continuous layer in young leaves and becomes hard and tough toward maturity. According to Eames and MacDaniels the surface of the cuticle is commonly smooth, (always so in the early stages) but when it matures it may be roughened

by cracks, by the breaking of scales or minute particles from the surface, and by small nodules or slight ridges and irregularities.

Curtis (7) has suggested the possibility that the cuticle may greatly reduce water loss when the stomata are closed. This statement implies that the cuticle, may not be entirely impervious to water. Referring to the movement of copper sprays and materials into the foliage of higher plants, Curtis stated that it may result from a partial weakening of the cuticle by the salt of the solution used.

Several investigators have reported that the cuticle is composed of lignified, cutinized, or suberized materials. Krausche and Gilbert (21) have suggested that the surface of the tomato leaf is composed of undifferentiated cellulose. They concluded that increased transpiration in the tomato leaf following copper spray or dust treatments takes place directly through the epidermal cell walls in spite of the presence of an apparently continuous cuticle. Assuming that the movement of water through the epidermis of the tomato leaf is non-polar or non-directional, the possibility of the movement of solutes with the water into as well as out of the leaf is suggested. In support of the concept that water may pass into the plant leaves from the atmosphere Stone, Went and Young (27) reported that "Negative Transpiration" may possibly account for the survival of Coulter pine in soil having a moisture supply below the wilting point for certain crops.

As further evidence of the fact that the cuticle is permeable to solutions of spray materials, Roberts, Southwick, and Palmiter (23) have demonstrated by means of a series of microchemical examinations of Mc-

Intosh apple leaves that cutin exist in lamellae parallel to the outer epidermal walls, but it by no means forms a continuous covering. The discontinuous spaces in the cuticular covering were found to contain pectinaceous substances which have great water absorption capacity. The pectinaceous substances were found to form a continuous path reaching from the outside of the leaf and extending to the walls of the "Vein Extensions". The following is quoted directly from their paper:

"The epidermal cell walls of the McIntosh apple leaf, therefore, can no longer be considered impervious to water. The amount and location of pectineaceous substances present in the leaves may have accounted for the rate of entrance of water soluble materials such as minor elements, nitrogen, hormones, and organic fungicides sprayed upon the apple trees. The epidermal layer of cells is closely connected to the small vein by means of vein extensions which lead directly to the large veins of the leaf."

Since the cuticle of the McIntosh apple leaf is not continuous, there is the suggestion that a similar situation may also exist in vegetable crops. If this assumption is correct, it may be accepted as a partial explanation of the means by which such rapid absorption of foliar applied mineral nutrients takes place in vegetable crops.

A close evaluation of recent work in leaf anatomy, linked with results obtained with experiments herein reported, indicate that leaf absorption is a physical rather than a physiological phenomena, and varies with the plant species. This concept is supported by two important observations. In the first place, leaf absorption as contrasted to root uptake was little influenced (Table XXII) by temperatures ranging from maximum to minimum for tomato plants, and secondly, the rate of leaf absorption was unaffected by light or darkness indicating little or no diurnal variation (31). Though not so simple, or rapid, leaf absorption may be likened to

moisture uptake by a sponge or blotter. It is likely that the degree and rate of uptake will vary with the nature of pubescence on the foliage, leaf surface area, physical and chemical nature of the leaf surface, all of which vary with plant species. The carbohydrate-nitrogen status in the plant may also be an important factor in foliar absorption.

Translocation of leaf absorbed nutrients was apparent under all conditions and plants studied. It was especially interesting to observe that rapid translocation of foliar applied nutrients was evident at temperatures ranging from 45° to 80°F. There is clearly a lack of correlation between temperature and phosphorus uptake and translocation from the leaves of tomato plants. The same is not true when phosphorus is applied to the soil. In this case it appears that phosphorus absorption and translocation from the soil decreases with decreasing temperature. These data indicate that phosphorus sprays may prove very beneficial either for crops which are normally grown during cool periods or for warm season crops which, for various reasons may be subjected to a cool environment during their early growth. This may well apply to crucifer and other crops grown during the winter months in the southern states, and warm season crops in the north.

As the disadvantages of soil application methods are pointed out, one must not be led to believe that nutritional sprays should replace them but rather they are suggested as supplements to soil fertilization. In the case of phosphorus, difficulty often arises because of the failure of this material to penetrate into the root zone. It may be positionally unavailable because of placement practices. Aware of the disadvantages

of soil applications, the grower is forced to apply considerably more fertilizer than he expects to recover in the current crop. Nutritional sprays may eliminate a portion of this waste of material as well as the labor and equipment involved in its application. It is true that some labor is required for foliage application, but where compatible materials are available they may be applied simultaneously with pest control sprays in accordance with the needs of the crop. This means that the machinery and expense normally required for insect and disease control may also provide for nutritional spray applications as will be required after emergence. According to the work of Silberstein and Wittwer (25) a much smaller quantity of phosphorus per acre is required for tomatoes when it is applied to the foliage than when it is applied broadcast on the soil. This is due largely to the elimination of losses by fixation.

It appears that nutritional sprays may probably come closer to giving the grower accurate control of the nutrient status of the plant than any method of soil applications yet devised. It is to be emphasized, however, that nutritional sprays are to be used as supplements to established soil fertilization practices rather than a replacement of them.

Utilization of Foliar Applied Sucrose

Data reported herein, indicate that sucrose sprays gave an increase in vegetative growth only at high temperatures and short photoperiods. These results are similar to those reported by Went and Carter. On the basis of these data it was first concluded, that high temperatures were necessary for foliar absorption of sucrose, and secondly, low light intensities resulted in deficient photosynthates in which case, the sucrose was

readily utilized. In a later experiment the first assumption was shown to be incorrect. Tomato plants apparently absorbed and utilized sucrose applied to the leaves, although they were held in storage at 50°F. This clearly indicated that factors other than temperature played a role in this phenomenon. Possibly light intensity and photoperiod were contributing factors. This was suggested by the fact that even at 80°F. sucrose sprays gave no indication of increased growth until the photoperiod was reduced to seven hours or less. In this connection, it is to be remembered that the tomatoes which were observed to utilize sucrose at 50°F., were held in complete darkness for 120 hours. Since the purpose was to determine the practicability of using sucrose sprays to offset the conditions of low light intensity and duration which are common to greenhouse culture in the northern latitudes of the United States, it must be concluded that such a practice is apparently of little benefit. This concept was further substantiated by data presented herein. In Table II one may notice that sucrose caused no significant increase in yield. Probably the failure of sucrose to show a significant gain over the control was the photoperiod which did not fall below eight or nine hours.

In many cases tomato plants are started in the southern part of the United States and shipped to the northern states where they are transplanted to the field after danger of frost has passed. According to Went and Carter(29):

"The long railroad transport weakens such plants, so that plants have to be hardened (which means generally: brought into a non-growing condition) if they are to withstand the shock of transplanting in addition to several days of darkness. As found in a small scale practical experiment, a sugar spray applied before shipping kept such plants in an excellent condition, and they did not suffer such a set back as the non-treated plants."

Experiments similar to those of Went and Carter were conducted at East Lansing, Michigan in 1949 and 1950 with results contrary to those reported by Went and Carter.

In 1949 tomato plants were sprayed with sucrose and subsequently placed in storage for 120 hours under conditions of temperature and light comparable to those prevailing during transit. The plants were then transplanted along with others which were comparable but did not receive the sucrose. Eight days after field transplanting a light frost occurred killing the buds and most of the leaves of the sucrose treated plants, while those sprayed with water were practically unaffected. At this time it was concluded that the absorption and utilization of sucrose during storage had caused the treated plants to revert from the "hardened" to an active growing condition; thereby, rendering them unable to endure the low temperature as did the control plants which were still relatively inactive. A similar experiment was conducted in 1950. The dates of field transplanting and prevailing climatic conditions for each follow:

1. May 20 - Very hot and relatively dry for four days, followed by rain and slightly cooler weather. Plants were watered as transplanted.
2. May 27 - High temperature and high soil moisture due to previous rains. Watering was not necessary.
3. June 3 - Moderate temperature and adequate soil moisture, followed by two days of warm cloudy weather. Transplanting took place in late afternoon.

4. June 13 - Warm, cloudy, and raining for next two days. Transplanting took place during rain.

5. June 23 - Light rain, no watering needed. Plants were set in afternoon followed by bright sunny days with high temperature.

Under these variable climatic conditions, the same general performance was observed with sucrose treated plants; e.g., a dying back of terminal buds and younger leaves later recovering by development of lateral branches from the stem axis. The pattern of injury following transplanting was similar to that observed in 1949 except it was more severe at low than at higher temperature. From these observations it appears that sucrose cancels the benefits of hardening thereby rendering the plants unable to withstand the shock of transplanting irrespective of climatic conditions. Inasmuch as it is now generally accepted that "hardening" of transplants is associated with increased carbohydrate reserves, and the fact that Went and Carter were able to produce sucrose treated plants which did not suffer normal set-back following transplanting, it is felt that further study is warranted.

Utilization of Foliar Applied Urea

Nitrogen is among the most important and most variable of the essential plant nutrients required for vegetable crops. It is needed in varying amounts by different crops, in varying amounts for the same crop during different seasons, and in varying amounts for the same crop depending upon the stage of maturity at which it is to be harvested. This means, of course, that the grower should have adequate control of

the nitrogen level in his plants at all times. This task is practically impossible where present methods of soil applications alone are employed.

From urea tolerance studies herein reported, it appears that vegetable plants grown in the field can withstand a higher concentration of urea solution than greenhouse-grown plants. This probably results from more favorable environment maintained under greenhouse conditions which result in the growth of a more delicate or succulent plant. After tolerances were determined an effort was made to determine if foliar absorption might completely replace root absorption. Results in Table XV indicate that this was not generally possible. In the second experiment where urea sprays were used in combination with soil treatments, the results were somewhat different. Urea sprays resulted in a significant increase over the control, but it was, at the same time, significantly less than that of plants which received adequate nitrogen in the soil.

This is more clearly evident where urea sprays were used on early celery grown on muck soil. In this case there was a tremendous quantity of reserve nitrogen. During the early spring the soil was apparently too cold for microbial activity and consequently, little nitrogen was available for root absorption. The plants which received leaf applications of nitrogen made an early start, while the control plants made very slow growth until the advent of warmer weather.

Utilization of Foliar Applied All-Soluble Complete Fertilizers

The growing interest in nutritional sprays has stimulated fertilizer manufacturers to place a relatively large number of water soluble formula-

tions on the market. Most of them are "complete" fertilizers containing nitrogen, phosphorus, and potassium and some also contain minor elements, hormones, and vitamins. An experiment was designed to test a few of them. The data (Table XXI) for this experiment indicated that there is no correlation between yield and analysis of the fertilizer materials when foliar applied. The complete fertilizer materials failed to give an increase over the control plants which were not sprayed with a nutrient solution. On the other hand, plants which were sprayed with urea nitrogen only, showed a considerable increase over those plants receiving the complete fertilizer formulation. These results raised some question as to the influence of the chemical form of fertilizer on ability to be absorbed and utilized when foliar applied.

Utilization of Foliar Applied Phosphorus and
Potassium as Revealed by Tracer
Techniques

As indicated in Figures 6A foliar applied phosphorus was absorbed very readily, and accumulated in the meristematic regions of the bean and squash seedlings. This was to be expected since phosphorus is used in the building of protoplasm and particularly for the formative stage of cell development. As cells grow older the percentages of carbonaceous material increase while the demand for phosphorus decreases. Cell ontogeny reveals that in the formative stage they are completely filled by the nucleus. This nucleus, while containing practically all of the phosphorus for a given cell, remains about the same size throughout subsequent stages. This is further explanation for the accumulation of phosphorus in the meristems (Figure 11).



Figure 11. Autoradiograms of bean plants showing the distribution of radioactive phosphorus in the plant subsequent to foliage and soil applications.

Top row, left to right: Plants harvested at 6, 24 and 48 hours after about 0.5 micro-curie of P^{32} was applied to one of the primary leaves.

Bottom row, left to right: Plants harvested at 6, 24 and 48 hours after five micro-curies of P^{32} were supplied to the soil.

This, however, does not apply to potassium. It is not generally required in the building of new protoplasm as is the case with phosphorus. Apparently, potassium must be present in sufficient quantities to perfect or catalyze the utilization of other nutrients. Figure 6B shows that potassium is absorbed and translocated rather evenly through the entire plant indicating that it does not necessarily accumulate in the more active regions as is the case with phosphorus. This point is emphasized merely to confirm the established concept of the role of potassium in plant metabolism.

Bean plants were used in an effort to determine the comparative rate of absorption and translocation of radioactive phosphorus when applied to the foliage and to the soil. In this case red kidney beans were planted in washed sand in four-inch clay pots. As soon as the first set of trifoliage leaves were beginning to open, one of the primary leaves was dipped in a 0.3 per cent solution of ortho-phosphoric acid containing one micro-curie of radioactive phosphorus per milliliter. About one half milliliter of the dipping solution remained on each leaf treated (determined by scaler counts per minute). A second group of bean plants was given fifty milliliters of a 0.3 per cent solution of orth-phosphoric acid containing one tenth micro-curie of radioactive phosphorus per milliliter or ten times, as much as was applied in the foliage applications. Samples were harvested at 6, 24 and 48 hours after treatment and prepared for autoradiograms according to the method of Wittwer and Lundahl (31). The results are presented in Figure 11. An important feature of this preliminary experiment was the fact that although approximately ten times

as much material was applied to the soil as to one of the primary leaves there was a greater accumulation in the vegetative apex when foliage applications were employed. This clearly indicates that up to 48 hours after treatment, there is a more rapid movement of phosphorus into the apex of beans from the foliage than from the soil. It was thought at one time that this phenomenon may have been due to the close proximity of the primary leaf to the apex. The plants in Figure 11 which were harvested at 48 hours after treatment erase this speculation by suggesting that the roots of the leaf treated plants contained a higher concentration of P^{32} than the roots which were standing in the radioactive medium. This indicates the possibility that root absorption of P^{32} is less rapid than is leaf intake of the same nutrient.

Relative efficiency of the utilization of phosphorus when applied by the two methods is also clarified. Within the 48 hour period, not only was absorption and translocation more rapid in leaf treated plants, but also the per cent of recovery was several times greater. This is indicated in Figure 11 where one tenth as much P^{32} applied to the leaf caused a more intense image in the apex than ten times as much applied to the soil. What accounts for this differential absorption? It has been reported repeatedly that soil applied nutrients are subjected to biological, colloidal, and chemical fixation (19). The sand media used, however, greatly minimized fixation phenomena. Probably no loss of soil phosphorus occurred through leaching. It is possible that much of the phosphorus may have been adsorbed as well as greatly diluted by the sand particles and consequently failed to come in contact with the roots.

If this is true, adsorption and dilution would have been much greater in a loam or clay soil because of greater surface area per square centimeter of media, and its greater water holding capacity. In cases where phosphorus is applied to the foliage, all disadvantages mentioned above are eliminated, leaving only those barriers which directly effect leaf absorption (thickness and chemical nature of cuticle, pubescence, etc.). At one time it was thought that the absorptive capacity of bean leaves may probably be greater than that of its roots. To justify this concept one must know first, the surface area of the root system and secondly, the amount of material being studied which actually reaches the root surfaces. Since the work herein reported did not provide for these detailed determinations, specific speculations are withheld. There is the suggestion, however, that leaf absorption is considerably more rapid and efficient. This is especially important where immediate results are desired, or where variable nutrient levels are desirable during the different stages of plant development within a given growing season.

SUMMARY

In a series of experiments the leaves of several vegetable crops were treated with nutritional sprays of sucrose, urea nitrogen, radioactive phosphorus, and radioactive potassium.

Sucrose sprays caused an increase in vegetative growth of tomatoes only when high temperatures (70° to 80°F.) were combined with short photoperiods (7 hours or less). The yield of ten varieties of greenhouse tomatoes grown in the winter of 1949-50 at 60°F. night temperature, and a nine to ten hour photoperiod was not increased by weekly foliar applications of 10 per cent sucrose solutions. Tomato plants which had been sprayed with 10 per cent sucrose solutions and stored for 96 hours at 50°F. suffered considerably more from the shock of subsequent field transplanting than did plants sprayed only with water.

Vegetable crops differ considerably in their ability to tolerate urea sprays. Variations in the greenhouse were from 0.4 per cent urea solution for cucumbers to 0.75 per cent for celery with only slight injury.

The yield of field tomatoes was significantly increased by four foliage applications of 0.6 per cent solutions of urea in the form of NuGreen. Greenhouse celery absorbed and utilized .75 per cent solutions of urea when sprayed on the leaves at temperatures ranging from 40° to 70°F. as indicated by total dry weight. Yields were increased significantly in early field celery plants by four foliage sprays of 1.0 per cent urea in the form of NuGreen. Applications of similar quantities of urea to the soil proved of little benefit.

Several all-soluble "complete" fertilizers sprayed on the foliage of commercially grown greenhouse tomatoes gave no significant indication of absorption and subsequent utilization. On the other hand, urea which contained only one (nitrogen) of the major nutrient elements gave a significant increase in yield.

Radioactive phosphorus applied to the primary leaves of beans and squash was rapidly absorbed and showed definite accumulation in the root tips and terminal buds within six hours after treatment. Potassium was found to be distributed more evenly over the entire plant.

The rate of absorption of radioactive phosphorus from the soil by tomato plants decreased as night temperatures were lowered from 75 to 45°F. Under the same conditions, absorption of radioactive phosphorus from the foliage was practically unaffected by temperature variations.

CONCLUSIONS

On the basis of experiments herein reported sucrose sprays, as a source of supplementary carbohydrates for tomato transplants or for commercial greenhouse tomatoes, are of no practical value.

Foliar applied urea-nitrogen is apparently absorbed and utilized by celery, tomatoes, beans, and squash as is evidenced by resulting growth and fruiting responses.

Environmental factors such as temperature may be less influential on the absorption and translocation of foliar applied than of soil applied nutrients.

The absorption and utilization of foliar applied nutrients likely varies with plant species, depending largely upon leaf anatomy, with emphasis on the chemical nature of the surface layer. Responding species probably absorb solutes through the entire leaf surface irrespective of stomata.

Nutritional sprays may be considered as supplements to soil applications but by no means a substitute so far as nitrogen, phosphorus and potassium are concerned.

The newness of the concept that sucrose, nitrogen, phosphorus, and potassium can be absorbed through the foliage of vegetable crops warrants continued and widely varied investigations.

BIBLIOGRAPHY

1. Arnon, D. I., P. R. Stout, and F. Sipos
Radioactive Phosphorus as an Indication of Phosphorus Absorption by Tomato Fruits at Various Stages of Development.
Amer. Jour. Bot. 27: 791-798. 1940
2. Biddulph, O.
Diurnal Migration of Injected Radio Phosphorus from Bean Leaves.
Amer. Jour. Bot. 28: 348-352. 1941
3. Bould, C. and J. Tolhurst
Report on the Use of Foliage Sprays for the Control of Magnesium Deficiency in Apples. Bristol Univ. of Agr. Res. Sta. Ann. Report 1948: 51-58. 1949
4. Boynton, D.
Foliar Nitrogen Sprays for Fruit Trees.
79th Ann. Rep. Mich. Sta. Hort. Soc.: 81-84. 1949
5. ———.
Studies on Control of Magnesium Deficiency in New York Apple Orchards. Amer. Soc. Hort. Sci. Proc. 46: 1-5. 1945
6. Calvin, M. and A. A. Benson
The Path of Carbon in Photosynthesis. Science N. S. 109: 140-142. 1949
7. Curtis, D. F.
Studies on Solute Translocation in Plants.
Amer. Jour. Bot. 16: 154-159. 1929
8. Eames, A. J. and L. H. MacDaniels
An Introduction to Plant Anatomy, Second Edition pp. 51-54.
McGraw-Hill Book Co., Inc. New York, 1947
9. Emmert, E. M. and Klinker
Spraying Tomato Foliage with Sucrose to Increase Carbohydrates and Protect Against Injury by Urea Sprays. Kentucky Agri. Exp. Sta. Bul. 550. 1950
10. Fisher, Elwood, Damon Boynton, and Kaare Skodvin
Nitrogen Fertilization of the McIntosh Apple with Leaf Sprays of Urea I. Amer. Soc. Hort. Sci. Proc. 51: 23-32. 1948

11. Fisher, E. G. and J. A. Cook
Nitrogen Fertilization of the McIntosh Apple with Leaf Sprays of Urea II. Amer. Soc. Hort. Sci. Proc. 55: 35-40. 1950
12. Hamilton, J. M., D. H. Palmiter and L. O. Weaver
Evaluation of Fermate for the Control of Apple Scab and Cedar-Apple Rust Fungi. Phytopathology 33 1943 (Abstract)
13. _____, _____ and L. C. Anderson
Preliminary Test with Uramon in Foliage Sprays as a Means of Regulating the Nitrogen Supply in Apple Trees.
Amer. Soc. Hort. Sci. Proc. 42: 23-126. 1943
14. Hayward, H. E.
The Structure of Economic Plants. pp. 10-11. The Macmillan Co., New York. 1948
15. Hemphill, D. D. and A. E. Murneek
A Preliminary Study of the Effect of Axillary Foliage on Yield of Tomatoes. Amer. Soc. Hort. Sci. Proc. 51: 359-361. 1948
16. Hevesy, G.
Interaction Between the Phosphorus Atoms of the Wheat Seedling and the Nutrient Solution. Ark. Bot. 33: 1946
17. Jenny, H. and R. Overstreet
Surface Migration of Ions and Contact Exchange. Jour. Physiol. Chem. 43: 1185-1196. 1939
18. Johnson, M. O.
The Spraying of Yellow Pineapple Plants on Manganese Soils with Iron Sulfate Solutions. Hawaii Sta. Press Bull. 51 1916
19. Jones, R. J. and H. T. Rogers
New Fertilizers and Fertilizer Practices. Advances in Agronomy 1: 36-76. 1949
20. Kramer, Paul J.
Plant and Soil Water Relationships, First Edition, pp 245-265. McGraw-Hill Book Co., Inc., New York 1949.
21. Krausche, K. K. and B. E. Gilbert
Increase in Transplanting Rates of Tomato Leaves Due to Copper Sprays. Plant Phys. 12: 853-860. 1937
22. Pink, L. A., M. S. Sherman, and F. A. Allison
The Behavior of Soluble Organic Phosphates Added to Soils. Soil Sci. 51: 351-365. 1941

23. Roberts, E. A., M. D. Southwick and D. H. Palmiter
Microchemical Examination of McIntosh Apple Leaves Showing
Relationship of Cell Wall Constituents to Penetrations of
Spray Solutions. Plant Phys. 23: 557-559. 1948
24. Sayre, C. B.
Starter Solution for Tomato Plants. New York State Agr. Exp.
Bul. 706. 1943
25. Silberstein, O. O. and S. H. Wittwer
Foliar Application of Phosphatic Nutrients to Vegetable Crops.
(In press) 1951
26. Spencer, V. E. and R. Stewart
Soil Penetration of Some Organic and Inorganic Phosphates.
Soil Sci. 38: 65-79. 1934
27. Stone, Edward C., F. W. Went and C. L. Young
Water Absorption from the Atmosphere by Plants Growing in Dry
Soil. Science III: 546-548. 1950
28. Weinberger, J. H., V. E. Prince, and Leon Havis
Test on Foliar Fertilization of Peach Trees. Amer. Soc. Hort.
Sci. Proc. 53: 26-28.
29. Went, F. W., and M. Carter
Growth Responses of Tomato Plants to Applied Sucrose.
Amer. Jour. Bot. 35: 95-106. 1948
30. Whiting, A. L. and A. E. Heck
Assimilation of Phosphorus from Phytin by Cats.
Soil Sci. 22: 477-497. 1926.
31. Wittwer, S. H.
Use of the Esterline-Angus Recorded in Plant Nutritional Studies
Utilizing Radioactive Isotopes. (Unpublished Data)
32. Wittwer, S. H.
Effect of Fruit Setting Treatment, Variety and Solar Radiation
on Yield and Fruit Size of Greenhouse Tomatoes. Amer. Soc. Hort.
Sci. Proc. 53: 349-354. 1949
33. _____ and W. S. Lundahl
Autoradiography as an Aid in Determining the Absorption and
Utilization of Foliar Applied Nutrients. (In press) 1951
34. Wolfenbarger, D. O.
Nutritional Value of Phosphatic Insecticides. Jour. Econ. Ent.
41: 818-819. 1949