INVESTIGATIONS ON THE USE OF FOLIAR APPLIED NUTRITIONAL SPRAYS ON SELECTED VEGETABLE CROPS

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INVESTIGATIONS ON THE USE OF FOLIAR APPLIED NUTRITIONAL SPRAYS ON SELECTED VEGETABLE CROPS

By

John Francis Kelly

AN ABSTRACT

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Approved by Robt. L. Carolus

Because of the recent interest in the practice of applying plant nutrients to the foliage of various plants, a series of investigations was conducted to determine the effects of several foliar treatments on vegetable crops. A review of available literature revealed that although the mechanism of absorption is unknown there is definite proof that nutrients are absorbed by leaves of many crops. Application of trace elements, magnesium and calcium to the foliage of several fruit and vegetable crops has become a standard cultural practice. Although nitrogen has been applied successfully to the foliage of certain fruit crops there have been few reports indicating that any of the three major elements, nitrogen, phosphorus and potassium can be advantageously applied to the foliage of vegetable crops. However, most investigators have not compared foliar applications with soil applications made at the same time. Because of the variation between and within species to environmental factors no general conclusions can be made concerning the factors affecting foliar absorption and injury.

Greenhouse experiments were conducted to determine some of the factors influencing susceptibility of tomatoes to injury by several fertilizer salt solutions applied singly and in combination with fungicides. Ammonium salts were found to be very injurious to tomato foliage as were several "complete" fertilizer solutions. Addition of fungicides or variation in the degree of hardening or soil water level had no effect on the susceptibility of tomato plants to injury by "complete" fertilizer sprays. In these tests nutrient sprays increased fresh weight of tomato plants 15 - 20% in seven days.

An experiment to determine the effects of foliar applied nitrogen, phosphorus and potassium-containing fertilizers on tomatoes in southwestern

Michigan revealed that although heavy applications of some of these materials increased phosphorus content of tomato petioles, as indicated by "quick tests", there was no effect on the nitrate-nitrogen or potassium content. These elements showed considerable variation in concentration throughout the season and exhibited obvious interactions. The treatments did not significantly affect yield. Another experiment to test the interaction of several methods of soil application of fertilizer with two foliar treatments to tomatoes, sweet corn and cucumbers resulted in no difference in nutrient content. Yields of cucumbers were reduced by foliar applied nutrients. Similar experiments on watermelons and muskmelons resulted in no apparent effects from treatment. Controls were given no additional fertilizer.

As a result of the investigations it was concluded that under the field conditions encountered foliar sprays of major nutrient elements are not beneficial but that they may be useful in plant-growing. However, with the available data, there is no basis for making specific recommendations for spraying N, P or K on the foliage of vegetable crops.

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INTRODUCTION

One of the fastest growing fields of plant science in recent years has been that of foliar nutrition, or as it is popularly termed, foliar feeding of plants. Some persons have been so impressed by favorable reports on the use of foliar sprays that they have failed to recognize this as a relatively unexplored field in which there are still many questions to be answered. A few have already suggested that perhaps foliar nutrition could largely replace the conventional methods of soil fertilization.

Many foliar spray materials have been placed on the market for sale to both home gardeners and commercial growers, which, though they are not misrepresented, have not been widely tested under conditions that prevail in the field or garden.

In order that their use be economically feasible it is important not only that the materials used be of reasonable cost, but also that they may be applied at little extra cost and, above all, that the materials produce the desired effect. Any additional costs must be compensated for with increased value.

It seems that the most practical means of applying nutrients to foliage would be to apply them along with regularly applied fungicides and insecticides. This, however, introduces the problem of compatibility of the fertilizer materials with the pesticides. Not only must these materials be compatible but they should not produce undesirable effects such as toxicity or antagonism, that would not occur when applied alone.

Sufficient work has been done to indicate that under certain conditions foliar nutrition may be practical. In fact, in some areas of

horticultural production it is now being used commercially. However, before this technique can be extended to other crops there are problems to be solved in addition to those of economics and compatibility. Among these are; tolerances of different plant species under various environmental conditions to various spray mixtures, methods of obtaining efficient coverage, and additives which may help to produce the desired effect or to prevent undesirable effects.

Of more academic interest are the energy relations involved in absorption of nutrients by above-ground parts and also the effects of this epicotyledonary absorption on the overall physical and chemical behaviour of the plant.

It was with the foregoing in mind that the investigations reported herein were initiated.

REVIEW OF LITERATURE

Although farmers in certain sections of Europe have been applying the liquid portion of animal and food wastes to the foliage of forage, pasture, and even salad crops for many hundreds of years, it was not demonstrated until very recently that much of the benefit of such treatment may be from nutrients absorbed through the foliage in much the same way as selective herbicides and growth regulators.

Mechanism of absorption - Wylie (137), in 1943, found that the epidermis of leaves is important for the conduction of water between the minor veins near the leaf surface. Shortly thereafter Palmiter, Roberts and Southwick (107,109) attempted to determine how spray solutions could penetrate apple leaves. They showed by microchemical technique that the epidermal cell walls are not covered by a continuous layer of cutin but that the epidermis is a laminated mass of discontinuous layers of cutin, cellulose and pectinaceous materials. The cutin is oriented parallel to the leaf surface and extends to the pectinaceous walls of the vascular tissue. They proposed that the pectinaceous extensions, being relatively hygroscopic, were avenues of conduction for foliar applied sprays.

Cook (23) and Wittwer (133) summarized the possible mechanisms of foliar absorption and concluded that the mechanism is still obscure. However, it can be concluded that the absorption is largely cuticular, though it may be in part stomatal (11).

That leaves can absorb water in large quantities from the atmosphere was demonstrated by Breazeale et al (14), who increased the water content of wilted tomato plants and of the dried soil in which they were growing by applying water in a mist form to the foliage.

Response of fruits and vegetables to calcium, magnesium and trace element sprays - There have been many reports in the literature on the use of foliar sprays to supply trace elements to plants. Much of this work has been performed on fruits for the correction of visible deficiency symptoms. The important economical applications of these practices with fruit are summarized by Boynton (11) and Cook (23). However, the practice of applying trace elements to vegetable crops has also become important since McLean (84) reported in 1927 that spinach could utilize foliar applied manganese.

It has often been observed that applications of fungicides and insecticides results in increased yields even in the absence of disease organisms (3,78,103). Heuberger (61) suggested that increased yields of tomatoes, potatoes, muskmelons and pickling cucumbers sprayed with zinc dithiocarbamate fungicides may have been due to absorption and utilization by the plant, of zinc, nitrogen or sulfur. It has been shown that zinc deficiency on tomatoes may be overcome by spraying the plants with Zineb (zinc ethylene bisdithiocarbamate) (36) or zinc sulfate (5,111). Townsend (125) corrected severe zinc deficiency symptoms on beans with zinc sulfate sprays. Only the plants which he sprayed produced a crop. A more detailed study of the absorption of zinc, iron, manganese, and copper from fungicides suggests that benefits other than disease control may account for response of tomatoes to fungicidal applications (89). Onions, on the other hand, were shown to be injured by foliar applications of zinc sulfate (32).

Spray applications of borax have been used effectively to correct boron deficiencies of sugar beets, table beets, rutabagas and turnips (15,79,80,81,129). Although borax sprays are effective in correcting deficiency symptoms of boron on rutabagas in Virginia, Shear (115) found that soil applications were more effective. On alkaline soils, on the

other hand, where boron is less available to plants, foliar applied borax is much more efficient and effective than soil applied borax for the correction of boron deficiency of rutabagas (54). Applications of borax with the regular fungicidal sprays have been used successfully on celery in Canada (62). Calcium nitrate or calcium chloride solutions can also be sprayed on celery for the correction of blackheart (47). Chucka and Brown (21) increased the yield of severely magnesium deficient potatoes by adding 60 pounds of magnesium sulfate to 100 gallons of the regularly applied Bordeaux Mixture. Furthermore, Johnson (66) and Davis and McCall (32) corrected deficiency of magnesium in celery grown on muck by foliar sprays of epsom salts, whereas the latter workers could not obtain response with soil applications. Also, Nylund (99) and Davis and McCall (32) were able to increase the yield of onions with foliar applications of 30 pounds per 100 gallons of water per acre of manganese sulfate. Ozaki (102) corrected the visual symptoms of manganese deficiency on snap beans and crowder peas by applying to the foliage manganese from various carriers. Gilbert (48) increased tomato yields on alkaline soil by as much as 215% by applying manganous sulfate to the foliage. Harmer and Sherman (55) increased yields of potatoes, onions, sugar beets, beans, celery and cucumbers with foliar applied manganese. Townsend and Wedgworth (126) found that spray applications of manganese sulfate were often more economical than soil applications to beans grown on slightly acid or alkaline peat soils. They rapidly corrected chlorosis caused by manganese deficiency with such sprays.

Evans and Troxler (38) decreased the incidence of blossom end rot of tomatoes by increasing the calcium level of the plants with foliar applications of calcium chloride. Geraldson (46) obtained similar results in

Florida. Stark (118) and Stark and Matthews (119) increased quality of muskmelons and increased both quality and yield of tomatoes with foliar applications of magnesium sulfate and borax. Kattan (69), on the other hand, found that this treatment in combination with Zineb produced no differences, but that chelated calcium did improve the color of tomatoes for processing.

That trace elements can be applied successfully and economically to certain vegetable crops has definitely been established by investigations such as those cited above. Applications of minor elements to the foliage have become standard cultural practices on several vegetable crops and there are many other possibilities for their use. It is also probable that success in the use of minor elements sprays stimulated interest in the use of foliar sprays to supply nitrogen, phosphorus and potassium to plants.

Fundamental research with N, P and K sprays - In 1936 it was reported that the phosphorus content of phosphorus deficient lettuce plants could be rapidly increased by spraying the foliage with potassium phosphate solutions (76). Wolfenbarger (136) showed that phosphatic insecticides may increase potato yields by contributing phosphorus to the plants. However, the first person to positively establish that phosphorus could be utilized if applied to leaves was Biddulph (6), in 1941. Studying the translocation of phosphorus in bean leaves, he was able to mechanically inject radioactive phosphorus into the leaves and trace its path through the plant. Similarly, Colwell (22) was able to make translocation studies with squash plants.

In 1943 Hamilton and his co-workers (52) reported that the fungicide Fermate (Ferric dimethyl dithiocarbamate) appeared to be of nutritional value to apple trees and suggested that nitrogen and other nutrients might be assimilated through the leaves of fruit trees. That same year they were able to increase both color and nitrogen content of apple leaves with foliar applications of urea solutions (53).

Silberstein and Wittwer (117) and Wittwer and Lundahl (134), working with various radioactive phosphorus carriers, reported definite absorption of foliar applied phosphorus by corn, tomatoes and beans. Oliver (101) obtained similar results with corn and beans. Asen, Wittwer and Hinsvark (1), also using radioactive phosphorus, obtained increased phosphorus content and increased growth from foliar sprays of phosphorus on Chrysanthemum plants. Kaindl (68), using similar methods on wheat and two dicotyledonous weeds, also demonstrated phosphorus absorption by leaves.

Mayberry (86) studied the absorption of foliar applied P^{32} and K^{42} by beans and squash and reported that phosphorus was absorbed and accumulated in areas of high metabolic activity while potassium was more evenly distributed after absorption. The work of Ticknor (124) supports this. Long, Teubner, Wittwer and Lindstrom (77) also used radioisotopes in their studies on the foliar absorption of phosphorus, potassium and rubidium. Swanson and Whitney (120), using P^{32}, K^{42}, Ca^{45} and Cs^{137} indicated that all were absorbed by the leaves of bean plants and that potassium was absorbed more rapidly than phosphorus. Wittwer (133) clearly summarized and tabulated the results of work done with radioactive isotopes in connection with non-root absorption of plant nutrients.

As a result of these fundamental studies it can be concluded that the major nutrient elements can be absorbed by the foliage of plants and that the use of radio-isotopes can be of great value in studying the behaviour of the materials applied.

Responses of fruits and vegetables to N-P-K sprays - Considerable research has been conducted to determine the effect of urea sprays on various fruit crops. Only with apples (4,7,12,24,27,40,41,42,43,52,96, 106,110,130) and citrus (19,20,64,73) have results been generally favorable. In some of these cases soil applications of nitrogen produced comparable effects. Results with nitrogen sprays on cherry (130,131), peach (16,33,74,96,98,132) and grapes (44,85) have been inconclusive. Foliar nutrition tests have also been conducted on tobacco (83,95,128) and several tropical and subtropical plants(18,94), many of which resulted in large benefits from foliar applied nitrogen. Use of phosphorus sprays on fruit crops has been limited and results are inconclusive (34,35,41,97). However, potassium sulfate sprays on potassium deficient apple trees in New York have corrected potassium deficiency symptoms (17). A "complete" N-P-K fertilizer accompanying fungicides on cacao decreased disease and increased the yield of cacao more than the fungicide alone (94).

One of the most promising uses for foliar applied nutritional sprays for applying the three major nutrient elements (N,P,K) is on plants grown on cold soils of northern growing regions. Evidence of this is supplied by reports from Russia and other European countries. In Russia, cabbage yields were increased with nitrogen containing sprays (29,127). Also, yields were increased and quality of tomatoes was improved by applying "complete" balanced nutrient sprays with micro-elements (121). In Hungary, Kuthy and his co-workers (72) increased fresh and dry weight of one month old lettuce plants by 10-25% by applying sprays containing "complete" N-P-K fertilizer or just a nitrogen fertilizer. They also increased pea yields 10% by spraying with P-K sprays during flowering. Peas did not respond when sprayed after pods were set.

Except in the above cases on cold soils there have been no reports which would warrant the use of foliar applied nitrogen, phosphorus or potassium on vegetable crops in place of soil applications. Some investigations do, however, suggest that these materials may be applied profitably as a supplement, particularly for the purpose of rapidly correcting deficiencies.

Geissler (45) sprayed pot-grown spinach with solutions containing nitrogen and potassium and estimated that all of the nitrogen, applied as ammonium nitrate, and 60% of the potassium, applied as potassium chloride, was absorbed. Thorne (122,123) increased the dry weight of swedes, barley, brussels sprouts, potassium deficient tomatoes and sugar beets by applying to the foliage a "complete" N-P-K solution made up of 1 part mono-ammonium phosphate: 5.3 parts potassium nitrate: 3.1 parts ammonium nitrate. French beans and apparently normal tomatoes, though they also absorbed the nutrients, did not otherwise show any response. In general, an addition of equivalent amounts of nutrients to the soil prior to planting was more effective in promoting growth. However, if the fertilizer had all been applied to the plants at the same stage of growth, soil applications might have given the same effects as foliar applications or might have been inferior.

McCall and Davis (82), working on organic soil, concluded that foliar applications of urea to celery gave no benefits but that onions, potatoes and table beets responded to such treatment although not as well as to soil applications. However, their data show that foliar applied nitrogen gave greater response per unit applied. Celery and onions did not respond to phosphorus sprays applied as ortho-phosphoric acid. Ozaki (104) and Ozaki and Carew (105) reported that applications of two to five pounds of urea with Ziram or Bordeaux mixture per 100 gallons of water per acre might be feasible for the correction of nitrogen deficiencies on tomatoes and beans when soil applications are not practical. However, under most conditions they found soil applications to be superior. Ozaki reported no benefits from spraying beans and tomatoes with phosphorus solutions as compared to soil applications.

Hester (58,60) and Isaacs and Hester (65) found application of urea sprays to be an effective means of supplying nitrogen to tomatoes and carrots. Others (66,90,93,114,118) report no advantage in spraying tomatoes with urea solutions as compared to soil applications of nitrogen. Mayberry and Wittwer (87), however, increased total yields of field and greenhouse grown tomatoes and the early yield of celery by spraying with urea, but did not increase yields of greenhouse grown tomatoes with an all-soluble "complete" fertilizer spray. Hayslip and Forsee (56) obtained similar results with N-P-K fertilizer sprays in the field when weather was fair, but following heavy, leaching rains they tripled tomato yields with foliar applications of nitrate of soda-potash. Danielson (31) applied urea solutions to the foliage of snap beans, radishes and spinach and a 1:2:1 fertilizer solution to potatoes, tomatoes, snap beans and lima beans but obtained no yield response. Sayre (113) dipped tomato plant tops into various starter solutions prior to transplanting. Nitrogen was apparently absorbed by the foliage as evidenced by the increased succulence but phosphorus deficiency symptoms developed shortly after transplanting. In an

experiment to determine whether or not a 23-21-17 fertilizer applied as a foliar spray could be substituted for regular soil applications of fertilizer to cabbage, lettuce and tomato, Ozaki (103) found that foliar spray application was either inferior to or no better than soil application. When phosphorus and potassium were supplied by the soil in adequate quantities for good growth, sprays containing only urea in solution were comparable to the "complete" sprays.

In Delaware a study of the economic feasibility of foliar application of nutrients to tomatoes, lima beans, potatoes, muskmelons and cucumbers was conducted over a four year period (13). Various combinations of fertilizer, fungicide, insecticide and sticker materials were applied to the crops. The only crop which responded favorably was tomato on unfertilized soil. It was concluded that foliar application of fertilizer materials is not economical or as effective as soil applications of fertilizers under Delaware conditions. However, it was not determined if the crops would respond to comparable soil applications.

Silberstein and Wittwer (117) tested several organic and inorganic sources of phosphorus in foliar sprays and increased growth of tomatoes, corn and beans but the only yield increase obtained was that of early tomatoes when sprayed with ortho-phosphoric acid or glycerophosphoric acid at a rate of only 2.73 pounds of P_2O_5 per acre. Learner (75) observed no significant differences with tomatoes sprayed with potassium chloride, urea or ortho-phosphoric acid except for the reduction of green placental tissue with the latter material. Wittwer, Teubner and McCall (135) later found bean and tomato leaves to be more efficient in the absorption of phosphorus than were roots, largely due to the

greater relative availability of the phosphorus. Bean leaves were much more efficient than tomato leaves in phosphorus absorption.

Although most investigations seem to indicate that foliar applications of nitrogen, phosphorus or potassium cannot replace soil applications of the materials to vegetable crops as a general cultural practice, conclusions of that nature are not justified. Most of the reported experiments were not adequately controlled. That is, it was generally not determined if the crops would respond to comparable soil applications. Factors other than nutrition could have been limiting crop response. In those cases in which comparable amounts of nutrients were applied to the soil the age of the plant at the time of application was not the same for both methods. However, there are indications that under certain unusual conditions foliar applications might be used successfully as a supplement to soil applications.

Factors influencing foliar absorption and injury - It is evident from the literature available that many factors interact to influence the rate and magnitude of foliar absorption. Very few species have been studied in this connection but it is obvious that there is not only great variation in response of different species to nutritional sprays as mentioned earlier, but also in the response within species to the many factors which affect foliar absorption.

Primary considerations in any discussion of rate of absorption by plants are the permeability of the cell walls to the materials to be absorbed and the factors influencing their accumulation in the cells. Therefore the following fundamental concepts of permeability and accumulation as summarized in basic plant physiology textbooks (28, 88) are presented. Few fundamental studies of these processes have been made on the plant parts involved in foliar absorption. In fact, very little such work has been done on meristematic regions, where most or all electrolyte absorption probably occurs. Most salts are absorbed and accumulated against a concentration gradient, the energy required for this process being supplied by the respiratory activities in meristematic regions. The mechanism responsible for this behaviour is not fully understood as is the mechanism of simple diffusion by which many organic solutes such as urea are absorbed. Since an adequate oxygen supply is most important to this process, foliar plant parts are never restricted in their ability to absorb salts by lack of oxygen. In general, salt accumulation is favored by increasing temperatures and concentration of sugars in plant cells. Cations, including NH_4^+, generally tend to accumulate more from an alkaline medium, whereas anions tend to accumulate more from an acid medium. Much work has been performed concerning cation antagonism but very little attention has been given to the influence of anions on salt absorption, although in general it may be stated that a rapidly penetrating ion of one charge will depress the rate of absorption of another ion of the same charge and increase the rate of absorption of an ion of the opposite charge.

Despite the large amount of work performed on plants to study cell wall permeability, there is no adequate explanation for this function. However, it is known that permeability is generally increased within limits by increases in temperature, light, toxic substances, mechanical injury, alkalies, cations of low valency, anions of high valency, frost hardening (particularly by previous exposure to low temperatures), and increased osmotic concentration within the cells. Although acids generally decrease cell wall permeability, if their concentration is

high enough they may cause cell injury, irreversible increases in permeability and subsequent death. Severe injury or exposure to toxins in high concentrations may have similar effects. The general effects of ions on permeability vary considerably with different plants and environmental conditions. Generally if the valency of the anion of a salt is greater than that of the cation, permeability is greater than if the reverse is true. However, if both ions are univalent, permeability is greater than if both or one of the ions are polyvalent. Increased permeability does not necessarily result in increased absorption.

It is generally agreed that an increase in the application rate and in the total number of foliar applications of nutrients increases the total quantity of nutrients absorbed (1,34,73), but Cook (23) found that varying the concentration of urea sprays from 1 to 2.5% did not affect rate or quantity of absorption. Another factor influencing the quantity of nutrient absorbed is the age of the plant or plant tissue involved. Volk and McAuliffe (128) found that leaves of young tobacco plants absorbed urea most efficiently and that the age of the specific plant tissue involved was not a determining factor. Others (18,23,43,73,117) have reported only that young tissue is more efficient in foliar absorption. Kaindl (68) stated that the optimum periods for absorption are periods of rapid plant growth. Several workers (12,18,23,24) have reported differences in the absorption capacity of the upper and lower leaf surfaces. They have found that the lower surface generally absorbs more rapidly. This has been attributed in part to the fact that the upper epidermis of the plants studied had fewer stomates. However, there may also be a difference in the rate of drying of the two surfaces due to exposure and differences in adhesion and penetration due to pubescence and cutinization. Cook and Boynton (24) reported that these differences between surfaces of apple

leaves were governed by the age of the tissue. They further reported that the upper surface absorbed more steadily than the lower surfaces so that after a relatively long period both surfaces absorbed the same amount. This may explain why others (110) found that the total amount absorbed was the same for upper and lower surfaces. Boynton (11) and Cook (23) discussed the possible explanations for the differences due to age and surface. They also discussed the possible effects of surface wetting and contact angle as causes of the variation between different plants in absorption and possible reasons for the effectiveness of wetting agents when used with urea (20,23,24,96).

The optimum temperature for foliar absorption varies with different plants, materials and conditions. Therefore apparent conflicts have been found in the literature. Cook (23) and Cook and Boynton (24) noted a tendency toward decreased absorption of urea at high temperatures. Ticknor (124) observed greater absorption of phosphorus by tomato stems at high temperatures. Kuykendall and Wallace (73) reported that citrus leaves absorbed urea at such a rate as to give a Q_{10} of 1.28. Swanson and Whitney (120) reduced mineral translocation in bean petioles by reducing the temperature. Mayberry (86) found that temperature did not effect foliar absorption. It has been generally concluded by some workers (68,77) that temperatures and other conditions favoring optimum growth also favor foliar absorption of nutrients. However, Asen, Wittwer and Teubner (2) found that the percent of phosphorus absorbed by the foliage of Chrysanthemums increased with decreasing temperature and level of phosphorus in the soil. They concluded that foliar applications of phosphorus gave their most beneficial effects under least optimum conditions for plant growth.

Since decreasing the vapor pressure deficit between the spray droplets on the foliage and the atmosphere increases absorption (23,24) it would seem that cool, moist weather favors absorption. Kaindl (68) found this to be true. Variations in absorption between night and day are subject to interaction with other factors that are governed by the time of day. Among these are temperature, relative humidity, sugar metabolism, incident radiation and changes in leaf morphology (133). Thus, as would be expected, there is variation in the effects of time of day on absorption (6,128). The same is true for the effect of exposure to darkness prior to spraying. Cook (23) and Cook and Boynton (24) kept apple trees in the dark prior to spraying with urea and failed to induce any greater absorption than by trees grown in the light. Long, Teubner and Wittwer (77) reduced absorption of phosphorus, potassium and rubidium by beans and tomatoes grown in the dark as compared to those grown in the light. Cook (23) observed more rapid absorption of urea by severely wilted apple leaves as compared with either slightly wilted or turgid leaves. Slight wilting did not affect absorption.

The practice of rewetting the foliage after nutritional sprays have dried is of questionable value. Absorption of foliar applied nutrients continues for a considerable time after it is applied, although the initial rate is most rapid (11,20,24,128,133). In some cases (20,24,43) rewetting has been reported to increase absorption but in many cases (34,123,130,133) there has been no response.

The pH of the nutrient medium has been shown to be a very important factor governing rate and quantity of absorption by leaves of citrus (20), apple (23,24), tobacco (128), tomatoes and bean (77). These investigations indicate that phosphorus is absorbed most efficiently at a pH between 2.0 and 2.5 and that urea is absorbed at a pH closer to neutrality.

Sufficient work has not been done to determine the effect of the nitrogen content of the plant on the rate of absorption of nutrients by foliage. However, Cook (23) and Cook and Boynton (24) did find that urea absorption was higher in apple leaves of high nitrogen content. On the other hand, Chen (20) found the opposite to be true with citrus leaves, and Norton (96) found that urea concentration in peach leaves had no effect on subsequent absorption. It has been shown by Wittwer, Teubner and McCall (135), working with tomatoes and snap beans, and by Eggert and Kardos (34), working with apple trees, that phosphorus absorption by foliage is greatest when the level of available phosphorus in the soil is low. Norton (97), however, indicated that the level of phosphorus in the tissue of strawberries had less effect on foliar absorption than on root absorption. Isaacs and Hester (65) stated that in order for tomatoes and carrots to utilize the nitrogen and potassium from foliar sprays the soil must be well supplied with phosphorus.

Another factor which may affect foliar absorption is the indicence of mechanical damage on the foliage as a result of disease, insects, weathering or machinery, all of which tend to increase absorption (11,128).

The relative value of the various sources of nitrogen, phosphorus and potassium have not been extensively studied. Thorne (122) using several vegetable crops, reported that nitrogen is absorbed equally well as an anion, a cation or in the unionized form and that nutrients when applied in different combinations are absorbed at different rates. Rodney (110) and Hamilton, Palmiter and Anderson (52) found the same to be true on apples but also reported that urea caused less injury to foliage than the inorganic ammonium salts and nitrates. Severe injury from nitrates may result from mixture with arsenate of lead, although

equal amounts of lime in the spray will prevent or reduce injury (52). Norton and Childers (98) added various inorganic nitrogen-containing salts to urea and obtained no additional response from peach.

Several investigators (43,77,97,116,117) using several plant species, have tested various organic and inorganic phosphorus carriers and report that ortho-phosphoric acid is the most readily absorbed form of phosphorus. Ammonium phosphates were generally found to be the most efficient salts. The potassium, calcium and sodium phosphates were generally inferior.

Geissler (45) reported that potassium chloride is superior to potassium sulfate as a foliar spray material for supplying potassium to spinach. Long, Teubner and Wittwer (77) found that potassium applied as a citrate at pH 8.0 was the best source of potassium. Ozaki (104) reported that fertilizer grade potassium chloride did not readily dissolve in water. Difficulties of this sort might be a factor limiting the use of certain chemicals in sprays.

Montelaro (90) points out the significance of controlling the rate of absorption of urea. He found that the amount of injury is proportional to the amount of urea which is absorbed within the first three to four hours after application. Thus by reducing the rate of absorption by the addition of magnesium sulfate he and his co-workers (90,91,92) were able to reduce foliage injury. It is possible that such protection is due to the formation of double compounds of urea (138). However, Ozaki (104), by measuring freezing point depressions of mixtures of urea and sucrose or magnesium sulfate concluded that double compounds are not formed by these mixtures.

Silberstein and Wittwer (117) reduced foliar injury by adding Dreft (a laundry detergent) to phosphorus sprays. This may be explained by the

work of Wittwer (133) and Swanson and Whitney (120), who found that wetting agents reduced phosphorus intake through the leaves of bean plants. Fisher and Walker (43), however, by adding wetting agents greatly increased phosphorus absorption by apple leaves.

Hinsvark, Wittwer, and Tukey (63), by measuring production of $C^{14}O_2$ by plants which had been sprayed with C^{14} labeled urea, were able to correlate urea hydrolysis with the rate of absorption and susceptibility to injury. They found that the plants with the highest apparent urease activity were those most easily injured by urea. Thus they found the following order from high to low susceptibility; cucumber, bean, tomato and corn. Mayberry (86), by actually observing injury at different concentrations of urea found the order to be similar; cucumber, bean, tomato and celery. He also found differences in susceptibility to urea between field and greenhouse grown tomatoes.

The actual cause of injury by nutritional sprays, other than the obvious effects of osmotic pressure and subsequent dessication, is not understood. Boynton, Margolis and Gross (12) suggest that urea injury may be a result of an accumulation of urea in the plant in toxic concentrations. The work of Cook (23) supports this idea. He found that 84% of the urea absorbed was still present in the leaf after eight hours, 65% after 24 hours and 43% after 48 hours. Because most of the urea sprayed on foliage is absorbed within a very short time (23,24) the concentration in the leaf could therefore become very high. It has also been demonstrated that toxic concentrations of biuret cause foliar injury after urea solutions have been sprayed on citrus (50,51,67,100), avacado (50,51), pineapple (112) and cherry (130,131). However, because all nitrogen compounds, especially free amino acids, increase after urea spray applications to tobacco (95), an accumulation of any of these beyond certain limits may also cause injury. This may not be the case in apple because it has been found that non-soluble nitrogen compounds do not accumulate but are translocated downward in the foliage (23,24). Norton (96) sprayed peaches four times with five pounds of urea per hundred gallons of water and observed as much injury as when he applied fifteen pounds at one time.

Noguchi and Sugawara (95) kept tobacco plants in the dark after applying urea. This resulted in injury which later disappeared when a sugar solution was applied to the leaves. This, they state, indicates that the carbohydrates necessary for nitrogen assimilation are supplied by the sugars. Other workers have reduced urea injury with sugars (23,24,37,71,92,105,114) or molasses (96,98). Cook (23) and Cook and Boynton (24) and Shaw and Hilton (114) attributed this protection to decreased rate of absorption of urea. Hinsvark, Wittwer and Tukey (63) found that sucrose also decreased hydrolysis of urea by leaves.

The effect of weather on degree of injury is not well known but Shaw and Hilton (114) did find that cloudy days with high relative humidity resulted in the greatest amount of foliage injury by urea, probably due to the greater increase in absorption.

Norton (96) decreased urea injury to peach foliage by adding cornstarch to urea sprays. He also found urea injury to be at a minimum above pH 5.5 Glycerol has been found to increase scorch on tomatoes (71). Grapes sprayed with urea and Bordeaux mixture showed less injury than grapes sprayed with urea alone (85). This along with the reduction of absorption of urea as affected by magnesium sulfate and calcium salts (23,96) indicates that the divalent ions may be responsible for this action (11). It has also been reported that by mixing urea and ammonium nitrate in equal proportions, the amount of nitrogen which can be safely applied to citrus, tomatoes and carrots can be increased twofold (64,65).

The investigation by Ozaki (104) on the tolerance of 14 vegetable crops to various inorganic salt solutions was the first detailed study of its kind on vegetable crops. He found that young and old tissue of tomatoes are equally susceptible to spray injury but that young tissue of bean plants is more susceptible than older tissue. He concluded that in general, vegetable crops that are easily injured by light frosts are most easily injured by foliar sprays.

Many of the workers previously cited used fungicides and insecticides in combination with the nutrients they applied. Few of them have made detailed studies of such combinations. Kelsheimer, Walter and Beckenbach (70), however, made recommendations for the combination of minor element compounds with insecticides and fungicides commonly used on beans, cucumbers, squash, tomatoes and peppers in Florida. Isaacs and Hester (65) reported that urea is compatable with the insecticides and fungicides commonly applied to vegetables. Ozaki (104) found that urea did not affect the toxicity of Parathion, Rotenone, Methoxychlor, Ziram or Bordeaux Mixture. When he mixed Parathion with urea sprays on beans the stems did not elongate; however, urea applied alone resulted in large increases in stem elongation.

No general conclusions as to the factors affecting foliar absorption can be drawn from the above cited studies because there is so much variation between and within species and because of the large number of factors which interact to influence foliar absorption. However, several methods have been found successful for the reduction of foliar injury, although little is known about the actual mechanism of foliar absorption and injury.

Effects of nutritional sprays on plant diseases - Beside their primary effect on the nutrition of plants, foliar nutritional sprays may prove to be useful in disease control or may be limited because of their stimulatory effects on disease. Cosper and Schuster (25) decreased the incidence of bean rust with urea sprays. Bloom and Walker (8,9,10) were able to either increase or decrease *Fusarium* wilt on greenhouse grown tomatoes with various fertilizer sprays. They found that *Fusarium* often developed more vigorously when the stimulating chemicals were applied after infection. In general those materials which decreased transpiration increased disease with increasing concentration of the material and vice versa.

EXPERIMENTAL OBJECTIVES

In the Summer of 1956 experiments were conducted at the Southwest Michigan Experimental Farm to study the effects of various methods of applying fertilizer to the foliage of tomatoes, sweet corn, cucumbers, watermelons and muskmelons. Commercially available "complete" liquid fertilizer and urea were used on tomatoes, sweet corn and cucumbers. Only the former material was applied to the melons. In addition KCl and $(NH_4)_2HPO_4$ were sprayed on tomatoes.

These materials were applied throughout the season at varying concentrations and observations were made to determine tolerances of the crops to the materials. In addition, plant tissue samples were analyzed periodically to determine the effect of treatment on the nutrient composition of the plants. Available yield data for the treatments were examined to determine what effect the spray applications had on production.

In the Fall of 1956 experiments were conducted in the greenhouse to determine the effects of several fertilizer materials applied to the foliage of tomato plants. The materials found to be safe for application to tomato foliage were tested for compatibility with fungicides under several conditions.

GENERAL EXPERIMENTAL METHODS

Field experiments were conducted on Oshtemo sandy loam soil at the Southwest Michigan Experimental Farm. Except for the treatments which were being studied, generally accepted cultural practices were used. Sprays were applied with a knapsack type sprayer. Unless otherwise specified all spray materials were applied at a rate of 100 gallons of water per acre.

Tissue samples were taken by selecting the third petiole of the leaf from the apex of randomly selected stems of the tomato plant. The midrib of the second youngest fully expanded leaf of randomly selected corn plants was used. Cucurbit tissue samples were made up of randomly selected petioles. Only living tissue, uninjured by previous foliar sprays was used. To prevent drying during transport the samples were kept in polyethylene bags. The tissue samples were rinsed with distilled water and dried by blotting in order to remove spray residues. This was not considered necessary if rainfall or irrigation was sufficient to remove residues before sampling.

The tissue samples were extracted with 2% acetic acid and analyzed by the methods outlined by Danielson (30). Colorometric and turbidimetric comparisons were made with a Bausch and Lomb Monochromatic colorimeter. Potassium determinations on all samples collected after July 19 were made with a Beckman Model B Flame Spectrophotometer. Determinations were made colorimetrically prior to this. Nutrient levels of soil samples were determined in the Soil Testing Laboratory.

Studies were made in the greenhouse on Stokesdale tomatoes which were seeded in flats on September 12 and transplanted to 4" clay pots on September 29. Sprays were applied with a one quart self-contained compressed air type sprayer. Both upper and lower leaf surfaces were sprayed uniformly until the spray solution dripped from the leaves.

Statistical comparisons were made by analysis of variance.

INVESTIGATION OF THE EFFECTS OF VARYING FERTILIZER RATIOS OF FOLIAR SPRAYS ON TOMATOES

Materials and methods - This experiment was conducted on a field of Rutgers tomatoes which, before planting, had been uniformly fertilized with 1000 pounds of 12-12-12 fertilizer, broadcast and disked in. The plants were spaced three feet apart in rows six feet apart. Prior to treatment (July 6) petiole samples contained 775 ppm NO_3- N, 154 ppm P, 5025 ppm K, 1743 ppm Ca and 204 ppm Mg. At the conclusion of harvest (Sept. 29) soil tests indicated a pH of 5.9 and eight pounds of available P, 55 pounds of K and 800 pounds of Ca per acre.

The following foliar spray treatments were randomized in three replicates of 13 plants each: (1) Control, (2) Tri-40 (1:2:1 ratio), (3) Urea + $(NH_4)_2HPO_4$ (1:2:0 ratio), (4) Urea (1:0:0 ratio) and (5) Urea + KCl (1:0:1 ratio). Table I summarizes the amounts of fertilizer materials applied at each date of treatment.

Petiole samples for analysis were taken from each plot on July 12, 19 and 26 and August 6 and 10 or 6, 7, 7, 3 and 7 days after treatment respectively. Mature marketable fruit was harvested for processing eight times between August 3 and September 18.

Discussion of results - Heavy applications of nutrients to tomato foliage on July 6, a warm (maximum temperature 79°F.) and sunny day, resulted in foliar necrosis. The damage incurred by $(NH_4)_2HPO_4$ was most severe. All leaves exposed to the spray were affected regardless of age. However, most of the necrosis occurred on the margins of the leaflets. The Tri-40 spray, applied at almost twice the recommended rate, produced similar but less extensive injury symptoms, that is, the burned margins were not so

Table I Schedule of foliar applications of nutrients to tomatoes.

Date	Treatment	Application (pounds per acre)			
		Material	N	P_2O_5	K_2O
July 6*	Tri-40[1]	37.3	3.7	7.4	3.7
	Urea[2]	6.6	3.0	--	--
	$(NH_4)_2HPO_4$[3]	19.4	4.1	10.4	--
	Urea, KCl	6.6, 5.3	3.0	--	3.3
July 12,19,26 Aug. 3,14,21	Tri-40	22.8	2.3	4.6	2.3
	Urea	5.0	2.3	--	--
	Urea, $(NH_4)_2HPO_4$	1.0, 8.3	2.3	4.6	--
	Urea, KCl	5.0, 3.5	2.3	--	2.3
Total for season	Tri-40	172.9	17.3	34.6	17.3
	Urea	36.6	16.5	--	--
	Urea, $(NH_4)_2HPO_4$	6.0, 69.2	17.7	37.6	--
	Urea, KCl	36.6, 26.3	16.5	--	16.8

*Applied in 85 gallons of water per acre.

[1] Tri-40 is a 10-20-10 analysis liquid fertilizer compounded of diammonium phosphate, urea, potassium hydroxide and small quantities of magnesium, manganese, zinc, copper and borax. The pH of the solution is 6.7. The weight of one gallon is 11.4 pounds. Its donation, for this experiment, by the Scope Chemical Company of Benton Harbor, Michigan is gratefully acknowledged.

[2] All the urea used in these investigations was Arcadian Urea 45, a 45% nitrogen, pelleted urea furnished through the courtesy of the Allied Chemical and Dye Corporation.

[3] Reagent grade diammonium phosphate and potassium chloride were used.

wide. The sprays containing urea and urea + KCl, both of which contained lower concentrations of chemically active ingredients than the other sprays, resulted in only slight marginal necrosis. Sprays on subsequent dates, when lower application rates were used, resulted in no visible injury.

The data in Table II indicate the nutritional level of the tomato plants as revealed by petiole composition, for five sampling dates as influenced by treatment. The application of nutrient sprays had no significant effect on the nitrate-nitrogen content of the tomato petioles (Table IIa). However, there was a tendency for the sprays to increase the nitrate content above that of the unsprayed control. Total soluble nitrogen contents although not determined on all samples, also showed only slight increases under the influence of treatment. Any nitrogen that was absorbed from the sprays was probably assimilated in the three to seven day periods prior to the time when tissue samples were taken and thus was not detected. A better index of nitrogen nutrition may have been obtained if total nitrogen content of the plant had been determined. Assuming that some of the nitrogen applied was absorbed and utilized in growth, the resultant dilution would account at least in part for the failure to detect increases in nitrogen or other nutrient elements. Another factor responsible for this apparent inability to increase nutrient levels might have been the time lapse from spraying to sampling.

The data in Table IIb indicate that phosphorus content was increased significantly on July 12 by the July 6 application of Tri-40 or $(NH_4)_2HPO_4$, the latter increasing the level significantly more than the former. Neither urea nor urea + KCl influenced the level of phosphorus when compared to the control. Along with a general decrease in phosphorus content on July 19,

Table II Effect of foliar treatment on tomato petiole composition.

a. Nitrate nitrogen (ppm)

	Dates of treatment					
	July 6	July 12	July 19	Aug. 3	Aug. 3	
	Date of sampling					
Treatment	July 12	July 19	July 26	Aug. 6	Aug. 10	Mean of 15 samples
Control	671	643	568	618	224	545
Tri-40	726	644	456	698	254	556
Urea	766	689	586	673	330	609
Urea, $(NH_4)_2HPO_4$	678*	744	553	944	233	631
Urea, KCl	658	618	466	894	256	579
Mean	700	668	526	766	260	584

b. Phosphorus (ppm)

Treatment	July 12	July 19	July 26	Aug. 6	Aug. 10	Mean of 15 samples
Control	121	56	185	126	113	120
Tri-40	248	95	170	170	111	159
Urea	138	64	193	115	81	118
Urea, $(NH_4)_2HPO_4$	332*	102	182	155	134	181
Urea, KCl	141	62	170	106	83	113
Mean	196	76	180	134	104	138

		Nitrogen		Phosphorus	
		.05	.01	.05	.01
L.S.D.:	Between treatments	N.S.D.	N.S.D.	16	23
	Between dates	154	206	62	83
	Interaction	N.S.D.	N.S.D.	27	37

*No urea applied July 6.

Table II (Cont'd.)

c. Potassium (ppm)

	Dates of treatment					
	July 6	July 12	July 19	Aug. 3	Aug. 3	
	Date of sampling					
Treatment	July 12	July 19	July 26	Aug. 6	Aug. 10	Mean of 15 samples
Control	2808	3425	3650	5828	7609	4666
Tri-40	2683	3850	3475	5711	7101	4570
Urea	3033	3283	3575	5869	7434	4641
Urea, $(NH_4)_2HPO_4$	2375*	3165	3341	5703	7234	4366
Urea, KCl	2783	3242	3575	6136	7659	4681
Mean	2737	3397	3523	5854	7414	4585
d. Calcium (ppm)						
Control	931	793	872	380	349	665
Tri-40	941	820	773	447	518	701
Urea	904	941	828	361	405	688
Urea, $(NH_4)_2HPO_4$	849*	785	762	384	564	669
Urea, KCl	943	955	647	383	380	662
Mean	914	859	777	391	444	677
e. Magnesium (ppm)						
Control	115	136	70	230	218	154
Tri-40	124	124	72	250	310	178
Urea	130	114	71	197	266	155
Urea, $(NH_4)_2HPO_4$	124*	149	87	217	247	166
Urea, KCl	127	125	70	207	251	156
Mean	125	130	74	220	258	162

		Potassium		Calcium		Magnesium	
		.05	.01	.05	.01	.05	.01
L.S.D.:	Between treatments	N.S.D.	N.S.D.	N.S.D.	N.S.D.	N.S.D.	N.S.D.
	Between dates	447	597	121	161	22	29
	Interaction	N.S.D.	N.S.D.	N.S.D.	N.S.D.	N.S.D.	N.S.D.

*No urea applied July 6.

possibly as a result of heavy fruit set, the plants sprayed with phosphorus on July 6 and 12 also showed decreases, yet they remained higher in phosphorus content than the others. This difference is possibly a result of the lasting effect of accumulated phosphorus or spray residue from the sprays applied July 6 and July 12. Since subsequent applications, supplying as much phosphorus as the July 12 treatment, did not increase the phosphorus level so markedly, it is probable that the lasting effect of the July 6 spray was a factor in maintaining the high level of phosphorus.

Although the effects of treatments applied after July 19 were less pronounced, the phosphorus-containing sprays again resulted in an increase in phosphorus level on August 6. This was only three days after application of sprays as contrasted with July 26 and August 10, seven and six days respectively after treatment, when there were no differences as a result of foliar sprays. On August 10, however, there were significant decreases in phosphorus content as a result of the urea and urea + KCl sprays. This may be explained on the basis of increased foliar absorption of urea as a result of the low general level of nitrogen on this date. The increased absorption of urea may have prevented absorption of phosphorus. However, this is not confirmed by increased nitrate-nitrogen levels as a result of these two treatments on August 10 (Table IIa). Therefore, it is more likely that increased vegetative growth as a result of urea absorption caused the phosphorus and nitrogen to be diluted.

The data indicate that the Tri-40 and $(NH_4)_2HPO_4$ both significantly increased the average phosphorus level of samples taken on the five dates between July 12 and August 10.

Potassium (Table IIc), calcium (Table IId) and magnesium (Table IIe) levels in the tomato tissue were not affected by the foliar sprays. Any potassium which may have been absorbed from the Tri-40 or KCl was either diluted in growth or translocated to other plant parts. There were no significant differences in magnesium levels as a result of foliar sprays, although Tri-40 did tend to increase magnesium levels in the tissue, possibly because of the small amount of magnesium contained in the material. Calcium levels did not vary.

As previously mentioned the failure of the tissue tests to indicate foliar absorption of the materials applied may be due to the time lapse between treatment and sampling. Therefore it is suggested that in future studies of a similar nature tissue samples be taken more promptly after treatment. Results of subsequent experiments described in this paper support this suggestion.

The data presented in Table II show that for all five nutrients studied there is significant variation between sampling dates. Figure 1 illustrates this seasonal variation of nitrogen and phosphorus. Except for the first date, when the highly concentrated phosphorus sprays exerted a great influence, and the last date when the maturing fruit likewise exerted an influence, high concentrations of nitrogen coincided with low concentrations of phosphorus.

Potassium concentration increased as the season progressed, whereas calcium decreased (Figure 2). Except for a sharp decline on July 26, magnesium concentration increased similarly to potassium concentration. The resulting relationship between potassium and calcium is as would normally be expected for any given date. Magnesium, on the other hand, in relation to potassium did not behave on a seasonal basis as it would at a given date in response to variations in potassium levels.

This seasonal variation is partially supported by the results of other

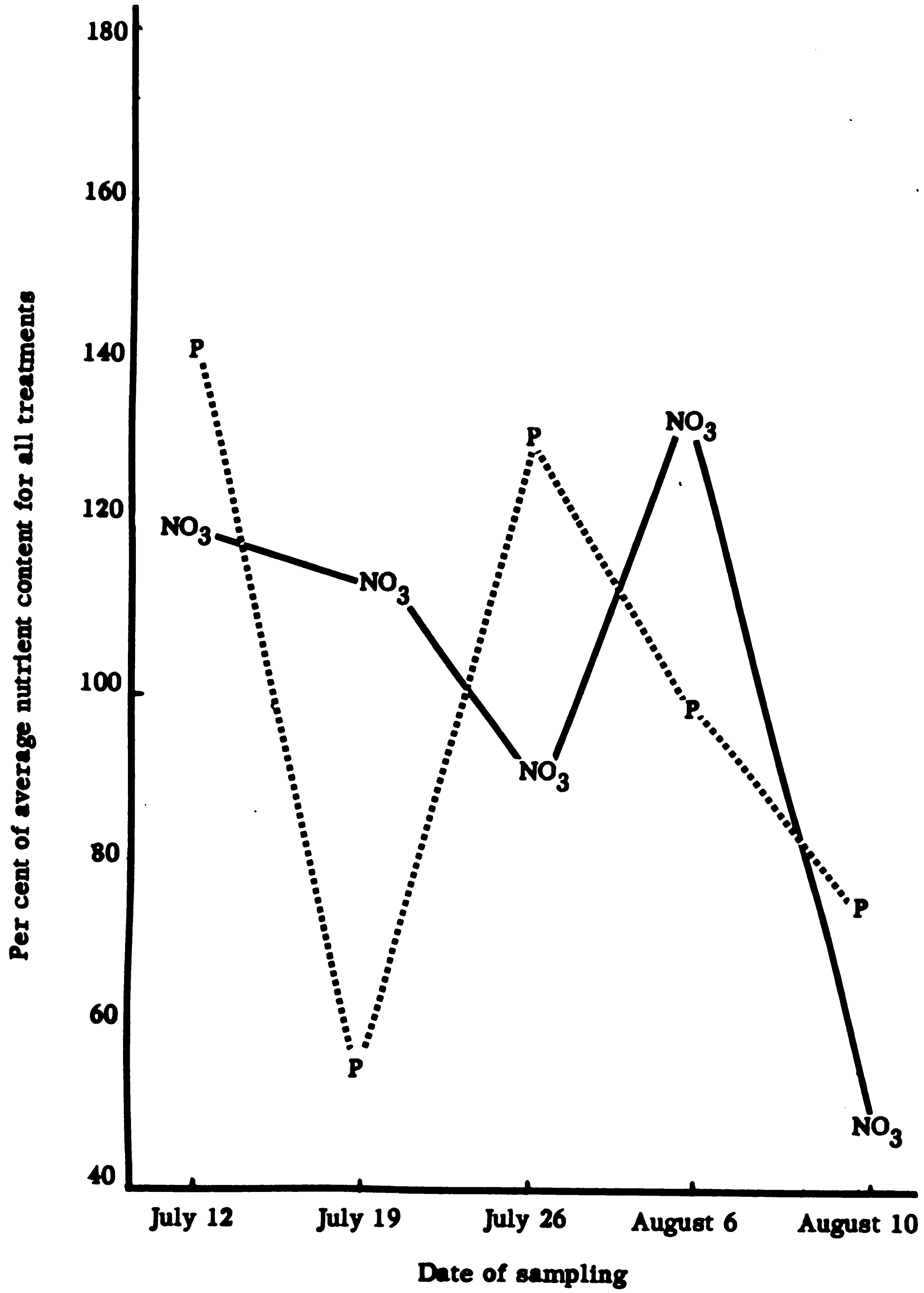

Figure 1 Seasonal variation in content of NO_3-N and P in tomato petioles.

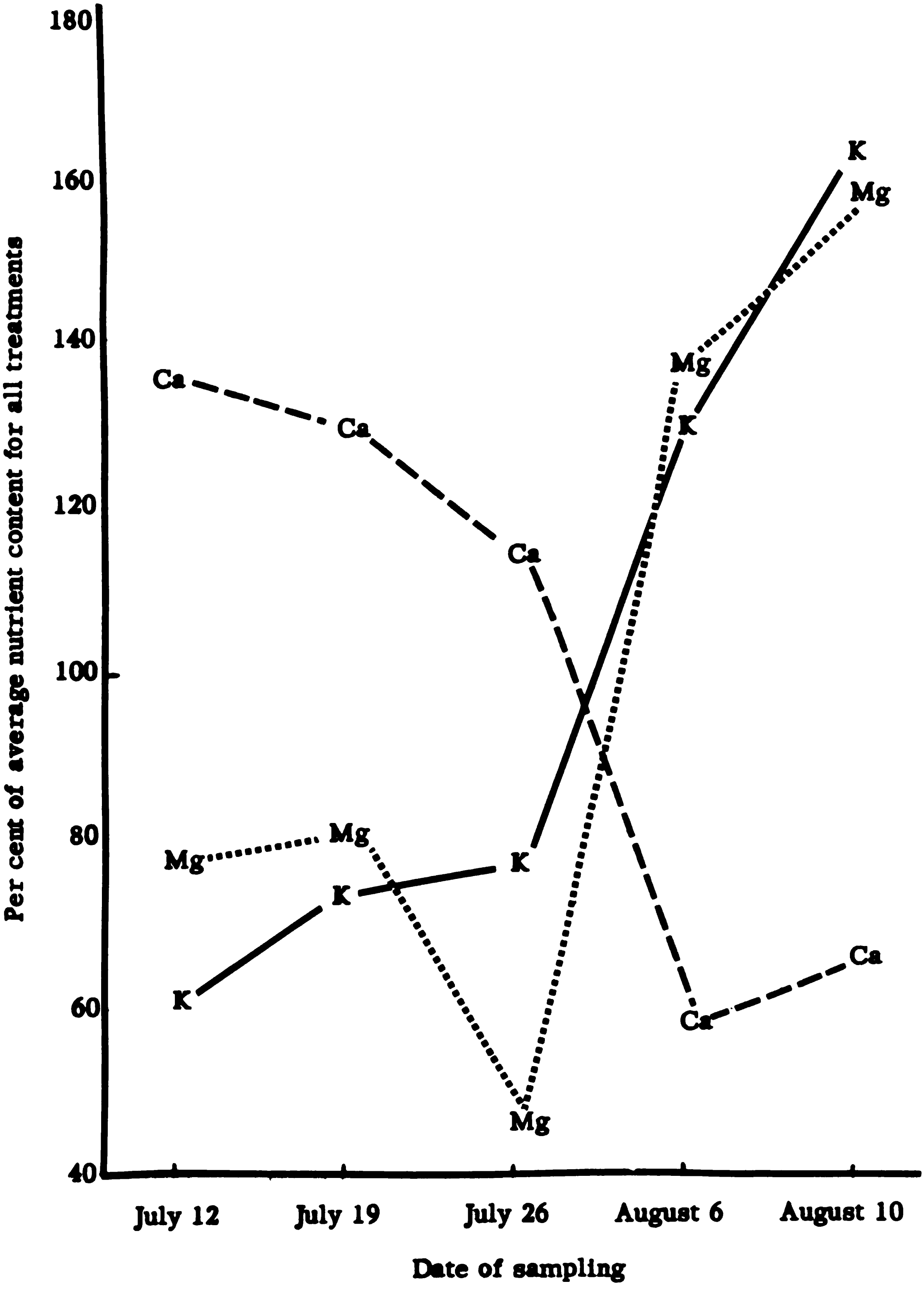

Figure 2 Seasonal variation in content of K, Ca and Mg in tomato petioles.

workers. It can be seen as a result of these investigations that many factors combine to cause seasonal variation in nutritional level. Dilution and utilization as a result of growth or increased water supply is no doubt important in causing variation in plant composition, particularly when measured on a fresh weight basis. Therefore it is unlikely that field results, with either soil or foliar applied nutrients, obtained at one location in a particular season can be duplicated.

Gilbert and Hardin (49) found that nitrate-nitrogen content of fresh tissue of several vegetable crops showed a large amount of fluctuation during the season. Phosphate-phosphorus content showed less variation and potassium even less, although tomatoes did tend to decrease in potassium content as the season progressed. Similarly, Hester (59) found that Rutgers and Improved Garden State tomatoes grown on sandy loam soil in New Jersey showed considerable variation in nitrate content, there being a general tendency downward later in the season. He reported no variation in phosphorus content, apparently because of the very high levels encountered, these reducing measuring precision. Potassium content fluctuated markedly throughout the season and in one case was higher and in another case lower in early August than in June and July. He also found that magnesium content was at a fairly high level in June after which it dropped sharply and then climbed steadily to a high level in August. Reeve and his co-workers (108) also found only slight variation in phosphorus content from July 13 to August 17. They did, however, report that nitrate-nitrogen content decreased sharply between July 28 and August 17.

Although much of the variation might have been caused by climatic changes and changes in growth rate, the results obtained indicate that the physiological age of the tomato plant might be an important factor in its

ability to absorb and accumulate nutrients. It appears that under the conditions of this experiment calcium was absorbed more readily by young plants and magnesium was absorbed more readily by older plants.

The figures indicate that the five nutrients studied were most nearly equal to the seasonal average nutrient content on July 26. Thus it appears that there is a certain stage in the growth of tomato plants when tissue analyses best indicate the average nutrient level for the season.

Table III indicates that the application of the foliar sprays had no apparent effect upon early yield, total yield or fruit size. Furthermore, throughout this experiment there were no visible differences in plant growth other than the injury incurred on July 6 by the first treatment. The control for this experiment was untreated. Therefore it is not known if the plants would have responded to a soil application. However, it is possible that there would have been a significant response had the plants not been injured.

Table III Effects of foliar treatment on fruit size, early yield and total yield of tomatoes.

Treatment	Yield (pounds per plant) (Mean of three 13 plant replicates) Early (Through August)	Total	Mean wt. of fruit (lb.)*
Control	0.90	4.74	.30
Tri-40	0.90	4.99	.32
Urea	0.70	3.90	.32
Urea, $(NH_4)_2HPO_4$	1.00	5.32	.27
Urea, KCl	0.77	4.24	.30
Mean of five treatments	0.85	4.63	.30

No significant differences at the 5% level

*Through September 4 picking.

EXPERIMENTS ON THE INTERACTION OF FOUR METHODS OF SOIL APPLICATION OF FERTILIZER WITH FOLIAR APPLICATIONS OF UREA AND A "COMPLETE" FERTILIZER

Materials and methods - Rutgers tomatoes, Golden Cross Bantam sweet corn and Marketer cucumbers were planted in alternating rows spaced 4 2/3 feet apart. Tomatoes were spaced three feet in the row, sweet corn was drilled uniformly 8-10 inches apart in 36 foot rows and cucumbers were seeded in hills three feet apart.

Two blocks were each divided into four main plots, each plot consisting of one row of each crop. In the Spring the plots were treated as follows:[1]

1) 900 pounds of liquid 8-8-8 Spring applied to rye cover and 400 pounds of dry 12-12-12 disked in at planting;
2) 600 pounds of dry 12-12-12 Spring applied to rye cover and 400 pounds of dry 12-12-12 disked in at planting;
3) 116 pounds of urea Spring applied to rye cover and 400 pounds of dry 12-12-12, 72 pounds of P_2O_5 as treble superphosphate and 36 pounds of K_2O each from KCl and K_2SO_4; and
4) 1000 pounds of dry 12-12-12 disked in at planting.

Each of these methods of application resulted in a total application of 120 pounds each of N, P_2O_5 and K_2O.

Each of the main plots was split so that a Tri-40 spray, a urea spray and a control plot appeared on each of them. The foliar treatments were applied at the rates, and on the dates indicated in Table IV. Petiole samples were taken periodically during the season from tomato and sweet corn plots. Cucumber petioles were sampled only on July 26 and their average composition was found to be 392 ppm NO_3-N, 256 ppm P, 2325 ppm K, 785 ppm Ca and 44 ppm Mg.

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[1] These treatments are referred to in subsequent tables as; 1) Liquid, dry (2 applications), 2) Dry (2 applications), 3) Urea, dry (2 applications) and 4) Dry (1 application).

Table IV Schedule of foliar applications of nutrients to tomatoes, sweet corn and cucumbers.

a. Tomatoes

		Application (pounds per acre)			
Date	Treatment	Material	N	P_2O_5	K_2O
July 6,17,26 & Aug.14	Tri-40	23	2.3	4.6	2.3
	Urea	5	2.3	--	--
August 6*	Tri-40	46	4.6	9.2	4.6
	Urea	10	4.6	--	--
August 21	Tri-40 + Urea	23 + 10	6.8	4.6	2.3
	Urea	15	6.8	--	--
Total for season	Tri-40 + Urea	160 + 10	20.6	32.3	16.1
	Urea	45	20.6	--	--

b. Sweet corn

July 6,17,26	Tri-40	23	2.3	4.6	2.3
	Urea	5	2.3	--	--
Total for season	Tri-40	69	6.9	13.8	6.9
	Urea	15	6.9	--	--

c. Cucumbers

July 26, Aug. 21	Tri-40	11.5	1.1	2.2	1.1
	Urea	2.5	1.1	--	--
August 3	Tri-40	5.75	0.6	1.2	0.6
	Urea	1.25	0.6	--	--
August 13	Tri-40	17.25	1.7	3.4	1.7
	Urea	3.75	1.7	--	--
Total for season	Tri-40	45	4.5	9.0	4.5
	Urea	10	4.5	--	--

*Applied in 200 gallons of water per acre

Mature, marketable tomatoes were harvested for processing six times between August 13 and September 13. Sweet corn was picked four times from August 27 to September 4. Cucumbers were harvested eight times between August 3 and August 31. Soil samples were taken from each of the main plots on September 29.

Discussion of results (tomatoes) - The data in Table V indicate that on each of the four petiole sampling dates there were no statistically significant differences in composition as a result of either soil or foliar treatment, although almost the same amounts of N, P and K were applied as in the previous experiment. There was no increase in phosphorus content as a result of Tri-40 application. This may be accounted for by the relatively high level of phosphorus in the soil (Table VI), which allowed even the unsprayed controls to accumulate a large quantity of phosphorus. Perhaps any phosphorus absorbed by the foliage resulted in a comparable decrease in root absorption.

As in the previous experiment, sampling the tissue earlier after treatment might have given different results. Eight days after the heavy application on August 6 there was not a significantly larger quantity of phosphorus in the plants which were sprayed with four gallons of Tri-40 per acre (Table Vd). Although urea sprays had no apparent effect on nitrate content, they did, as in the previous experiment, tend to decrease phosphorus accumulation on August 14, particularly when urea was applied to the soil.

On August 6 (maximum temperature 74°F.) and August 21 (maximum temperature 77°F.) sprays were applied in concentrations greater than those which resulted in severe injury in the previous experiment. Yet there was no visible injury. This apparent resistance was due partially to the

Table V Effects of foliar sprays on tomato petiole composition.

a. July 6 (soil treatment effects)

	Petiole composition (ppm) (Mean of two replicates)				
Treatment	NO_3N	P	K	Ca	Mg
Liquid, dry (2 applications)	685	182	3500	749	200
Dry (2 applications)	680	210	3588	839	220
Urea, dry (2 applications)	650	198	3488	831	220
Dry (1 application)	838	202	3550	888	352
Mean	713	198	3531	827	248

No significant differences at the 5% level.

b. July 26 (foliar treatment effects)

Control	675	223	3012	532	78
Tri-40	668	223	2875	442	93
Urea	562	220	2412	510	72
Mean	635	222	2767	495	79

No significant differences at the 5% level.

Table V (Cont'd)

c. August 14 (effects of all treatments)

Soil treatment	Foliar treatment	NO_3N	Petiole composition (ppm) (Mean of two replicates) P	K	Ca	Mg
	Control	349	64	6000	292	347
Liquid, dry	Tri-40	233	155	5675	262	284
(2 applications)	Urea	233	132	6175	314	309
Mean of three foliar treatments		272	117	5950	289	313
	Control	325	142	6050	280	280
Dry	Tri-40	330	133	5738	328	318
(2 applications)	Urea	360	78	5900	303	317
Mean of three foliar treatments		338	114	5896	305	305
	Control	356	101	5775	308	284
Urea, dry	Tri-40	280	119	5912	330	317
(2 applications)	Urea	280	39	5625	360	341
Mean of three foliar treatments		309	86	5771	333	314
	Control	398	108	5500	361	319
Dry	Tri-40	495	75	5950	352	333
(1 application	Urea	488	72	5825	274	326
Mean of three foliar treatments		462	85	5758	329	326
Mean of four soil treatments						
	Control	357	104	5831	310	307
	Tri-40	338	120	5819	318	313
	Urea	344	78	5881	314	323
Mean of all treatments		345	100	5844	314	314

No significant differences at the 5% level.

d. September 3 (foliar treatment effects)

Treatment	NO_3N	Petiole composition (ppm) (Mean of two replicates) P	K	Ca	Mg
Control	258	90	8062	306	575
Tri-40	258	78	8338	300	510
Urea	173	86	8112	294	455
Mean	230	81	8171	300	513

No significant differences at the 5% level.

Table VI Nutrient level of soil as influenced by soil treatment.*

Treatment	pH	Pounds per acre of: (Mean of two replicates) P	K	Ca
Liquid, dry (2 applications)	6.2	24	70	1000
Dry (2 applications)	6.2	30	70	1000
Urea, dry (2 applications)	5.9	26	86	800
Dry (1 application)	5.8	32	73	1000
Mean	6.0	28	75	950

No significant differences at the 5% level.

*September 29

increased size and vigor of the plants on these dates, the sprays being distributed over a larger leaf area. No doubt, the differences were also a function of the temperature, the relatively low temperatures resulting in less rapid absorption, and injury.

Despite heavy applications of nitrogen on August 21, the sprayed plants were no higher in nitrates than the non-sprayed controls on September 3. As in the previous experiment, N, P and Ca contents decreased, whereas K and Mg contents increased as the season progressed.

As indicated by Table VII there were no statistical differences in early yield, total yield or fruit size as a result of either soil or foliar treatments. Since the controls were untreated it is not known that the plants would respond to any fertilizer treatment. However, there was a tendency for the Tri-40 to increase both early and total yields.

Discussion of results (sweet corn) - The data presented in Table VIII summarize the nutrient level values found in sweet corn leaf tissue as affected by various soil and foliage treatments. With the exception of calcium, no statistically significant differences in the level of any nutrients studied were associated with treatment. Calcium level, however, was found to vary with the soil treatments. The treatment did not affect the pH or Ca content of the soil. Therefore, the differences in calcium appear to be unrelated to the levels of N, P, K and Mg in the plant tissue or to the calcium supply from the soil. However, the dry 12-12-12 did contain some calcium in the filler which may have been more readily available to the plants although not present in quantities large enough to greatly influence the calcium content of the soil. Thus the plants on the plots receiving all their fertilizer as 12-12-12 were higher in calcium than those receiving part of their fertilizer in the liquid, urea, treble

Table VII Effects of treatment on tomato yield and fruit size.

Soil application	Foliar application	Yield (lbs./plant) of two 12 plant plots Early	Total	Mean wt. of fruits (lb.)*
	Control	1.9	3.9	.35
Liquid, dry	Tri-40	2.0	3.7	.32
(2 applications)	Urea	1.9	4.2	.34
Mean of three foliar treatments		1.9	3.9	.33
	Control	1.6	4.0	.36
Dry	Tri-40	2.2	4.4	.32
(2 applications)	Urea	1.9	4.0	.32
Mean of three foliar treatments		1.9	4.1	.33
	Control	1.6	4.0	.34
Urea, dry	Tri-40	1.8	4.3	.35
(2 applications)	Urea	2.0	4.8	.33
Mean of three foliar treatments		1.8	4.4	.34
	Control	1.8	3.7	.30
Dry	Tri-40	2.4	4.7	.33
(1 application)	Urea	1.3	3.2	.38
Mean of three foliar treatments		1.8	3.9	.34
Mean of four soil treatments				
	Control	1.7	3.9	.34
	Tri-40	2.1	4.3	.33
	Urea	1.8	4.1	.34
Mean of all treatments		1.9	4.1	.34

No significant differences at the 5% level.

*Through Sept. 4 picking.

Table VIII Effects of treatment on sweet corn leaf midrib composition.

a. July 6 (soil treatment effects)

	Leaf midrib composition (ppm) (Mean of two replicates)				
Treatment	NO_3N	P	K	Ca**	Mg
Liquid, dry (2 applications)	830	100	4575	370	143
Dry (2 applications)	745	98	4500	672	155
Urea, dry (2 applications)	630	116	4638	494	156
Dry (1 application)	680	92	4538	542	144
Mean	721	102	4562	520	149
**Significant differences at the 1% level					
L.S.D.:			.05	.01	
			61	112	
All other nutrients - no significant differences at the 5% level.					

b. July 26 (foliar treatment effects)

Control	660	92	3275	748	56
Tri-40	478	128	3100	680	56
Urea	565	154	3088	660	76
Mean	568	125	3154	696	62
No significant differences at the 5% level.					

superphosphate, KCl or K_2SO_4 forms, none of which contain calcium.

Because of the smooth surface and generally vertical orientation of corn leaves, a large portion of the materials applied to the foliage did not adhere, although some of the material did roll into the stem apex. This suggests the need for using both a spreading and a sticking agent to increase adherance.

Table IX shows that none of the treatments affected sweet corn yields on either a weight or count basis.

Discussion of results (cucumbers) - Although there were no visible signs of injury as a result of foliar application of nutrients, and tissue analyses were not made to determine their effect on plant composition, there were apparently internal physiological reactions which resulted in reduced yields (Table X). Tri-40 and urea decreased yields of marketable slicing cucumbers by 35 and 25% respectively. These differences were significant at the 10% level. These differences were not a result of increased yields of unmarketable fruits. It is of interest to note that despite relatively light individual applications of Tri-40 and urea (Table V), the cucumber, which has been found to be very intolerant of heavy applications of nutrients to the foliage (63,104), responded negatively to these relatively low concentration sprays of Tri-40 and urea. Neither Tri-40 nor urea sprays produced any visible effects in the plants at any stage of the experiment. Plants which showed typical nitrogen deficiency symptoms did not change in appearance when either urea or Tri-40 was applied.

Table IX Effects of treatment on yield of sweet corn.

Soil treatment	Foliar treatment	(Mean yield of two replicates) Tons/acre	Dozen ears/acre
Liquid, dry (2 applications)	Control	4.84	1513
	Tri-40	4.48	1356
	Urea	4.57	1461
Mean of three foliar treatments		4.61	1457
Dry (2 applications)	Control	5.30	1660
	Tri-40	4.55	1461
	Urea	5.10	1597
Mean of three foliar treatments		4.98	1573
Urea, dry (2 applications)	Control	4.15	1324
	Tri-40	4.00	1250
	Urea	4.85	1639
Mean of three foliar treatments		4.33	1405
Dry (1 application)	Control	4.19	1345
	Tri-40	5.32	1681
	Urea	4.69	1534
Mean of three foliar treatments		4.73	1520
Mean of four soil treatments			
	Control	4.62	1471
	Tri-40	4.57	1437
	Urea	4.80	1558
Mean of all treatments		4.67	1489

No significant differences at the 5% level.

Table X Effects of treatment on yield of cucumbers.

Soil treatment	Foliar treatment	Yield (bu./acre) (Mean of two 11 hill replicates) Marketable	Unmarketable
Liquid, dry (2 applications)	Control	156	74
	Tri-40	90	56
	Urea	92	79
Mean of three foliar treatments		113	70
Dry (2 applications)	Control	237	62
	Tri-40	126	62
	Urea	133	78
Mean of three foliar treatments		166	67
Urea, dry (2 applications)	Control	127	95
	Tri-40	137	99
	Urea	164	72
Mean of three foliar treatments		143	89
Dry (1 application)	Control	168	80
	Tri-40	95	80
	Urea	125	63
Mean of three foliar treatments		129	74
Mean of four soil treatments			
	Control	172	78
	Tri-40	112	74
	Urea	129	73
Mean of all treatments		138	75

L.S.D.		.10	.05
	Between foliar treatments	41	N.S.D.
	Between soil treatments		N.S.D.
	Interaction		N.S.D.

INVESTIGATION OF THE EFFECTS OF A "COMPLETE" NUTRITIONAL SPRAY ON WATERMELONS AND MUSKMELONS

Materials and methods - Nine varieties of watermelons, planted in hills six feet apart in rows seven feet apart on sandy loam soil, were sprayed with Tri-40 three times according to the schedule recorded in Table XI. Treatments were replicated twice. Petiole samples were collected for analysis on July 12 and 19, both at intervals of one week after treatment. Severe hail injury on July 26 forced abandonment of the experiment.

Preston Honeyrock muskmelons planted in hills spaced five feet apart in rows seven feet apart were sprayed on July 17 at rates of 0, 1/2 and 1 gallon of Tri-40 per acre. Distributed among the apparently normal plants were some with light brown, circular, hardened spots approximately one-half inch in diameter evenly spaced on the older leaves. The lower surface of the leaves had an abrasive texture. Whole leaf tissue samples of both normal and abnormal plants were analyzed as were petioles of randomly selected plants prior to treatment. Hail injury also prevented continuation of this experiment.

Discussion of results - The July 5 (maximum temperature 70°F.) application of one gallon of Tri-40 in 50 gallons of water per acre caused no visible injury to watermelons. However, two gallons per 50 gallons applied July 12 (maximum temperature 84°F.) resulted in slight marginal necrosis on the leaves. Two gallons in 100 gallons of water on July 19 (maximum temperature 76°F.) caused no visible injury.

Analyses of petiole samples collected on July 12 and 19 indicated that the nutritional level of the plants was not affected by treatment (Table XII). It is likely that only a small fraction of the major element requirements

Table XI Schedule of foliar applications of nutrients to watermelons and muskmelons.

a. Watermelons

Date	Pounds per acre of Tri-40	Gallons per acre of water	Application (pounds per acre) N	P_2O_5	K_2O
July 5	11.4	50	1.1	2.2	1.1
July 12	22.8	50	2.3	4.6	2.3
July 19	22.8	100	2.3	4.6	2.3
Total of three dates	57.0	--	5.7	11.4	5.7

b. Muskmelons

July 17	5.7	100	.55	1.10	.55
July 17	11.4	100	1.10	2.20	1.10

Table XII Effects of foliar treatment on watermelon petiole content.

	Spray		ppm of (Mean of two replicates)			
Date	treatment	NO_3N	P	K	Ca	Mg
	Tri-40	778	79	3279	2152	138
July 12	Untreated	706	83	2982	2188	140
	Mean	742	81	3131	2170	139
	Tri-40	645	38	3075	1447	139
July 19	Untreated	835	25	2912	1444	122
	Mean	740	32	2994	1446	130
	Tri-40	712	59	3177	1800	138
	Untreated	771	54	2947	1816	131
	Mean	741	57	3062	1808	135

No significant differences at the 5% level.

of watermelons can be supplied through the foliage because although there is a large total leaf area the foliage is still subject to injury from sprays of low concentration. Later in the season when deficiencies are likely to occur it would not be feasible to spray the plants because of the mechanical injury which would result. Furthermore, there were no visible differences between sprayed and unsprayed plots.

One application of either 1/2 or 1 gallon of Tri-40 per acre to muskmelons on July 17 did not cause visible foliage injury, nor did it change the appearance of the plants described avove as abnormal. Analyses of both normal and abnormal leaves yielded no clue as to the cause of the disorder (Table XIII). This table illustrates the importance of uniform sampling of plant parts for nutritional studies. The concentration of nitrate-nitrogen and potassium were higher, whereas phosphorus, calcium and magnesium concentrations were lower in the leaf petiole as compared to the whole leaf. This suggests that a sample of tissue from a certain plant part may not be indicative of the overall nutritional status of the plant. For each element studied there is no doubt a different plant part which should be sampled for valid comparisons.

Table XIII Nutrient levels of muskmelon petioles.

Source of tissue	ppm of NO_3N	P	K	Ca	Mg
Random petiole samples*	718	67	4580	2,498	219
Whole leaf samples,** normal plants	325	119	1050	10,800	402
Whole leaf samples,** abnormal plants	230	119	1100	9,624	348

*Mean of five samples.
**one sample.

INVESTIGATION OF THE EFFECTS OF VARIOUS IONS ON THE FOLIAGE OF TOMATOES

Materials and methods - Stokesdale tomato plants, five weeks from seeding, which were approximately one foot high were sprayed as indicated in Table XIV. Each treatment was applied to three plants. After treatment the plants were kept in a greenhouse with night temperatures maintained at 65°F.

$NH_4Cl + K_2SO_4$ and $KCl + (NH_4)_2SO_4$ were both dissolved in water to give a 1:0:1 N, P_2O_5, K_2O ratio. In order to determine which components of these soultions would result in injury the salts were also applied singly at varying concentrations (Table XIV). One series of plants (A) was sprayed three times. Series B was sprayed once.

Injury incurred by the sprays was observed and noted periodically for nine days following treatment. In this and the subsequent investigation plant injury was rated numerically as follows:

0 - No injury
1 - Marginal wilt of leaves
3 - Marginal necrosis of leaves
5 - Severe marginal necrosis of leaves
7 - General necrosis of leaves
9 - Severe general necrosis, plant near death
10 - Death of entire plant

Values of 2, 4, 6 or 8 were assigned when the degree of injury was intermediate between the above values.

Discussion of results - The effects of treatment on the foliage of treated plants are recorded in Table XIV. The differences in intensity of injury between the sprays with high and low concentrations of salts and between

Table XIV Effect of treatment of tomato foliage with salt solutions.

						Index of injury*						
						Series A**					Series B***	
Treatment	Molal conc. (1x)	Pounds per 100 gallons NH_4^+	K^+	Cl^-	SO_4^{--}	Oct. 21	Oct. 22	Oct. 23	Oct. 24	Nov. 1	Oct. 24	Nov. 1
NH_4Cl + K_2SO_4	.07 .01	1.08	.67	2.09	.83	1.0	2.0	3.0	3.0	6.0	0	2.0
KCl + $(NH_4)_2SO_4$	.02 .03	1.08	.67	.67	2.92	2.0	2.0	3.0	3.0	3.0	0	3.0
NH_4Cl	.07	1.08	--	2.09	--	2.0	2.7	4.0	4.0	5.7	0	3.3
$(NH_4)_2SO_4$	.03	1.08	--	---	2.92	2.0	2.7	3.0	3.0	4.0	0	2.0
KCl	.02	---	.67	.67	---	0	0	0	0	3.0	0	0
K_2SO_4	.01	---	.67	---	.83	0	0	0	0	0	0	0
NH_4Cl	.02	.33	---	.67	---	0	0	0.7	0.7	3.3	0	1.0
$(NH_4)_2SO_4$	.01	.33	---	---	.83	0	0	0	0	1.0	0	0
KCl	.07	---	2.34	2.09	---	0	1.0	2.0	2.0	3.0	0	0
K_2SO_4	.03	---	2.34	---	2.92	0	0	0	0	0	0	0
Control	---	---	---	---	---	0	0	0	0	0	0	0

*Mean for three plants

**Series A	Date and time of treatment	Weather	Concentration
	Oct. 20, 12 noon	Cloudy, cool (65°F.)	1x
	Oct. 22, 12 noon	Clear, warm (85°F.)	2x
	Oct. 23, 6:00 p.m.	Cool (65°F.)	2x
***Series B	Oct. 23, 6:00 p.m.	Cool (65°F.)	2x

the dates of application indicate that factors other than concentration and temperature are important in determining susceptibility to injury. The most severe and rapidly appearing injury occurred on plants in series A when the lower concentration was applied on a cool day. Subsequent sprays applied to the same plants, although of higher concentration than the first spray, did not markedly increase injury within four days of their application. One application of the more highly concentrated spray to series B plants on a cool evening did not result in any visible injury until one week after treatment. These results suggest that the internal condition of the plant, perhaps as influenced by hardening prior to treatment and many other factors, controls the degree of susceptibility to salt injury.

The data further indicate that the intensity of injury by a given salt solution varies with the source of ion or with the interaction of ions. Although osmotic concentration is a factor in determining amount of injury it is apparently not as important as the presence of particular ions. In both series A and series B, solutions of equal or nearly equal osmotic concentration resulted in dissimilar degrees of injury. For example, K_2SO_4 (.02 molal) caused no injury, whereas NH_4Cl (.01 molal) resulted in injury in both series.

Injury occurring after treatment with KCl was not observable as early as was injury from sprays containing NH_4^+. Injury was most pronounced in the presence of NH_4^+ and Cl^- ions, particularly when applied as NH_4Cl. However, NH_4^+ ions applied at high rates resulted in severe foliar injury even in the absence of Cl^- ions.

All injury associated with NH_4^+ ions began as a wilting of the leaflet edges followed by necrosis of varying extensiveness and then by a bright yellow chlorosis progressing toward the midrib (Figure 3B). In the early stages, injury incurred with KCl was similar, but the subsequent chlorosis was less striking but more generally distributed over the leaf (Figure 3C).

These results suggest that the injury observed was largely a result of NH_4^+ or NH_3 toxicity resulting from an accumulation of these materials in the plant cells. It is possible that Cl^- ions increase the permeability of the cell walls to NH_4^+ and that the resultant rapid absorption causes accumulation faster than the ions can be utilized or translocated.

K_2SO_4 was the only material tested which was safe for application to tomato foliage at relatively high rates. However, due to its low degree of solubility in water its use in concentrated liquid sprays would be limited.

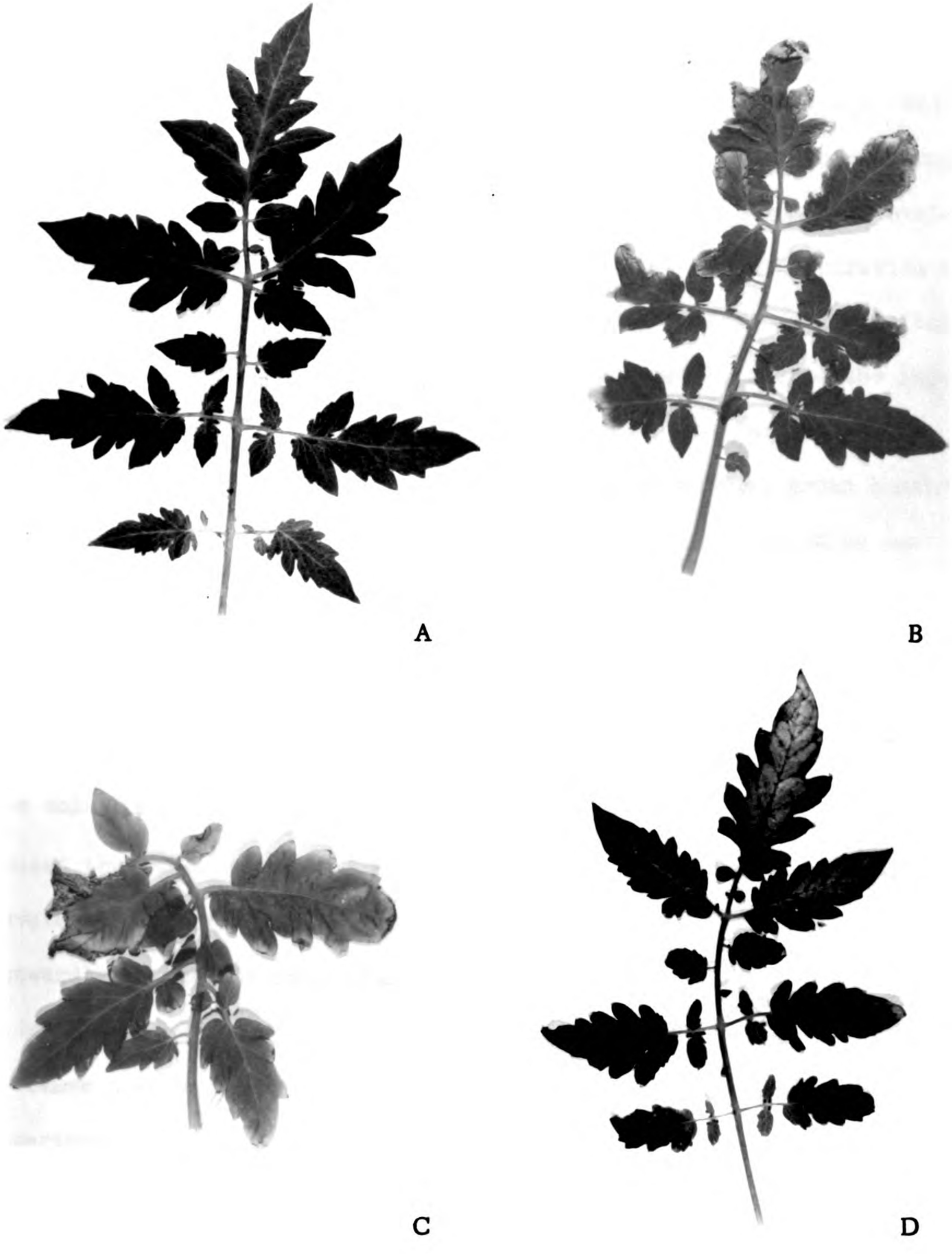

Figure 3 Effects of foliar nutritional sprays on tomato foliage; A. Normal, B. NH_4Cl injury, C. KCl injury, D. Injury from 1:2:1 ratio spray composed of $(NH_4)_2HPO_4$, KOH and KCl.

INVESTIGATION OF THE EFFECTS OF "COMPLETE" FOLIAR SPRAYS APPLIED SINGLY AND IN COMBINATION WITH FUNGICIDES

Materials and methods - The effects of eleven 1:2:1 N, P_2O_5, K_2O ratio fertilizer solutions on tomato foliage were studied. The composition, source materials and some properties of the solutions tested are stated in (Table XV). Eight of the sprays were applied at 1x concentration to field grown tomatoes in September as a screening test to determine the tolerance of tomato foliage to them. In an attempt to reduce the injury caused by solutions #5, #6 and #8, solutions #5a, #6a and #8a were formulated and tested at 1.5x concentration on greenhouse grown tomatoes. Solution #5a substituted Mg for Na as the NO_3 carrier. Solution #6a substituted H_3PO_4 for Na_2HPO_4 and reduced the pH. Solution #8a had its pH raised by substitution of KOH for KCl. These solutions were also unsatisfactory. At the same time these three solutions were tested the remaining solutions (#1, #2, #3, #4 and #7) were given the same test. The solutions with a specific conductance less than 250 (Mhos x 10^{-5})[1] caused the least injury. After two weeks plants treated with solution #4 developed a chlorotic pattern which began at the midrib and progressed outwardly to the margins. Unaffected areas were dark green (Figure 3D). Older leaves were affected first. Solutions #1, #2, #3 and #4 were found to cause the least foliar injury and were selected for use in the following experiment.

The fertilizer sprays were applied at the concentrations given in Table XV. Applied at a rate of 100 gallons per acre the solutions would supply 5 lbs. of N, 10 lbs. of P_2O_5 and 5 lbs. of K_2O per acre. Manzate

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[1] Determined with a Solu-bridge.

Table XV Composition and properties of "complete" nutrient solutions.

Solution #	Composition 1x	Molarity	Specific Conductance*	pH	Amount of injury (screening tests)
1	$(NH_4)_2HPO_4$ KNO_3 KCl	.169 .090 .037	219	8.1	None
2	$NH_4H_2PO_4$ KNO_3 Urea	.169 .127 .066	160	5.5	None
3	H_3PO_4 KOH Urea	.169 .127 .214	100	2.9	10%
4	$(NH_4)_2HPO_4$ KOH Urea	.169 .127 .045	171	9.4	10%
5	$NaNO_3$ KH_2PO_4 H_3PO_4	.428 .127 .042	278	2.5	60%
5a	$Mg(NO_3)_2$ KH_2PO_4 H_3PO_4	.214 .042 .127	300	2.0	30%
6	NH_4Cl K_2SO_4 Na_2HPO_4 NH_4NO_3	.091 .064 .169 .169	342	7.9	25%
6a	NH_4Cl K_2SO_4 H_3PO_4 NH_4NO_3	.091 .064 .169 .168	420	1.8	30%
7	K_3PO_4 $(NH_4)_2HPO_4$ NH_4NO_3	.042 .127 .087	215	8.0	10%
8	KCl NH_4NO_3 H_3PO_4	.127 .214 .169	360	1.7	20%
8a	KOH KCl NH_4NO_3 H_3PO_4	.064 .064 .214 .169	280	2.0	50%

*Mhos x 10^{-5} of solution diluted 20 fold.

(manganese ethylene bisdithiocarbamate), zineb (zinc ethylene bisdithiocarbamate) and basic $CuSO_4$ with spreader adhesive (34% Cu), when used, were applied at rates of 2, 2, and 3 lbs. per 100 gallons, respectively.

The experiment was designed to study the interaction of the following factors:

5 fertilizer treatments (Solutions #1, #2, #3 and #4 and a control),

4 fungicide treatments (Manzate, Zineb, Copper and a control),

2 levels of soil moisture (plants in soil saturated with water by placement of pots in one inch of water seven days prior and three days following treatment and plants watered normally), and

2 states of hardening (small plants, gorwn for three weeks at 55°F. night temperature and larger, more succulent plants grown continually at 65°F. night temperature prior to treatment).

Each treatment was applied to three plants in two replicates, one in a 55°F. and the other in a 65°F. night temperature greenhouse. Effects of treatment on index of injury and fresh weight of plant tops were determined after one week.

The mixture of Manzate with solutions #2 and #4 resulted in excessively rapid flocculation which might prevent their use. Addition of solution #4 to copper spray material turned the mixture from a cloudy green to a clear blue, apparently from the formation of a copper ammonium complex at the high pH. Acidification with HCl restored the mixture to its original condition.

Discussion of results - As evidenced by the data in Tables XVI and XVII fertilizer spray solutions increased the fresh weight of tomato plants and resulted in foliar injury. The effect of the fertilizers on the fresh

Table XVI Analysis of variance of fresh weight and index of injury as influenced by treatment.

		Fresh weight		Index of injury	
Source of variation	Degrees of Freedom	Sums of squares	F	Sums of squares	F
Total for treatment	159	45,837	---	11,822	---
Replication	1	3,209	7.57	10	2.00
Water level (W)	1	1,789	4.14	4	<1
Error (a)	1	432	---	5	---
Total for water level	3	5,490	---	19	---
Hardening (H)	1	26,497	43.15*	6	<1
H x W	1	1,363	2.22	11	1.69
Error (b)	2	1,228	---	13	---
Total for hardening	7	34,578	---	49	---
Fungicide (F)	3	564	3.42*	26	<1
Fertilizer Spray (S)	4	1,865	8.49**	1,462	5.15**
F x S	12	567	<1	71	<1
F x W	3	43	<1	4	<1
F x H	3	716	<1	0	<1
S x W	4	201	<1	33	<1
S x H	4	15	<1	17	<1
S x H x W	4	100	<1	11	<1
F x H x W	4	106	<1	3	<1
S x F x W	12	717	<1	52	<1
S x F x H	12	1,169	1.09	48	<1
S x F x H x W	12	1,077	1.77	33	<1
Error (c)	75	4,119	----	------	----
Error (d)	145	------	----	10,285	----
Correction factor		416,466		9,828	

*Significant at the 5% level.
**Significant at the 1% level.

Table XVII Effects of treatment of tomato foliage with fertilizer-fungicide mixtures of two levels of hardening and water content.

	Fresh weight/plant**	Index of injury*
a. Effects of fertilizers (means of 96 plants)		
Control	15.3	0.00
Solution 1	18.7	2.20
Solution 2	17.7	2.26
Solution 3	16.8	2.71
Solution 4	16.6	0.90
Mean	17.0	1.61
b. Effects of fungicides (means of 120 plants)		
Control	17.8	1.58
Manzate	16.2	1.71
Zineb	16.7	1.75
Copper	17.3	1.41
Mean	17.0	1.61
c. Effects of water (means of 240 plants)		
Saturated by sub-irrigation	18.1	1.67
Surface watered	15.9	1.56
Mean	17.0	1.61
d. Effects of hardening (means of 240 plants)		
Hardened	12.7	1.55
Succulent	21.3	1.68
Mean	17.0	1.61

L.S.D.	.05	.01	.05	.01
Between fertilizers	1.2	1.6	.40	.86
Between fungicides	1.1	N.S.D.	N.S.D.	N.S.D.
Between water levels	N.S.D.	N.S.D.	N.S.D.	N.S.D.
Between degrees of hardening	5.6	N.S.D.	N.S.D.	N.S.D.

*From 0 (no injury) to 10 (death).

**Grams

weight and amount of injury was not altered by plant hardening, soil moisture level or fungicides. Both hardening and limiting the water supply to the plants tended to reduce injury by the fertilizers. The differences, however, were not statistically significant. Regardless, even if there had been statistical significance, the actual differences between indices of injury were not large enough to markedly influence plant growth. This is true in spite of the difference in size between the hardened and the succulent plants. Apparently the threshold of injury would occur at a lower concentration for large, succulent plants than for small, hardened plants. Probably the threshold of serious injury which would stunt the plant would also occur at a lower concentration in succulent plants. However, the injury observed in this experiment occurred within a range between these thresholds. Therefore the differences were not large. Further, even though a temperature difference existed between the two replicates they did not differ significantly with respect to average fresh weight or index of injury.

All fertilizer solutions resulted in foliar injury; solution #4 causing significantly less than the others and solution #3 significantly more. The apparent protection from severe injury, afforded by solution #4, is likely a function of the high pH of the solution. This condition might have reduced the rate of absorption of the chemicals, an important factor in the control of foliar injury. However, the nutrients apparently were utilized, as indicated by an increase in the fresh weight of the plants. The severe injury incurred with the application of solution #3 was possibly a result of protein coagulation at a low pH. This solution had the lowest specific conductance of all the solutions tested; supporting the finding in the previous investigation that osmotic concentration is not the only

factor determining the occurrence of spray injury. The severity of burning or its distribution apparently prevented the plants from gaining in fresh weight as they did from treatment with solutions #1 and #2, both of which caused less injury than solution #3.

Because of the large number of treatments applied there was necessarily a difference in the time of application. Thus, solutions #1 and #2 were applied early in the afternoon under the influence of higher light intensity and temperatures than were solutions #3 and #4. However, results indicate that time of application was not a contributing factor determining degree of foliar injury.

Although they did not significantly affect foliar injury, both Manzate and Zineb decreased plant growth, whereas copper did not significantly affect it. However, both copper and Zineb caused the foliage of the plants to which they were applied to turn dark green, even in the absence of fertilizer. The combination of fungicides with fertilizers did not significantly affect the influence of the fertilizers on the fresh weight of plants. The data recorded in Table XVIII indicate that copper tended to be least harmful in combination with fertilizers, whereas Manzate and Zineb were most injurious when applied with fertilizers. With increased numbers of applications to the same plants these tendencies might be accentuated.

A total of eight plots were sprayed with the spray which contains fertilizer solution #1 and Manzate. In five of these plots, including all four plots that were surface-watered, the plants were constricted at the soil level and did not stand straight up, two of the plants being dead. This abnormality was not observed in other fertilizer-fungicide combinations. Since the Cl^- ion is the only ion which is present in solution #1, but not in the other solutions and all other components of solution #1 occur in

Table XVIII Effects of combination fertilizer and fungicide sprays on the fresh weight of tomato plants.

Fungicide	Fresh weight per plant* (means of 24 plants) Fertilizer spray Control	Sol'n. 1	Sol'n. 2	Sol'n. 3	Sol'n. 4	Mean of fungicide treatments
Control	15.3	20.4	18.2	18.3	17.0	17.8
Manzate	15.6	17.1	16.8	15.3	16.2	16.2
Zineb	15.8	17.8	17.6	16.4	15.8	16.7
Copper	14.5	19.6	18.0	17.2	17.3	17.3
Mean of fertilizer treatments	15.3	18.7	17.7	16.8	16.6	17.0

*Grams

other solutions in combination with Manzate, it is possible that the Cl^- reacted chemically with some component of Manzate to produce a toxic substance which dripped down the stem and accumulated at the base of the plant. However, the leaflet tips, which also accumulated spray material, were not injured more than other plants sprayed with solution #1. It is also possible that a toxic substance was formed, absorbed by the plant and translocated to the hypoctyl region where its movement into the roots was interfered with. This problem requires further investigation.

In general, plants sprayed with fertilizer solutions were lighter green and taller than plants not sprayed with fertilizer. This may have been a result of an excess of potassium, although if the nitrogen was not absorbed it could have been a nitrogen deficiency. The 1:2:1 ratio which was applied, although apparently at least in part utilized, would not improve the condition of the plants for subsequent transplanting. The increased "legginess" would result in considerable mechanical injury during transplanting. By varying the composition of the fertilizer, however, different effects could be produced. Furthermore, if more light had been available to the plants, the responses obtained might have been more pronounced.

DISCUSSION AND CONCLUSIONS

Under certain conditions the practice of applying calcium, magnesium and trace elements in sprays to the foliage of vegetable crops has become established. However, beneficial effects from foliar applied nitrogen, phosphorus or potassium have not been widely observed. There have been few cases reported where foliar application of nitrogen, phosphorus or potassium has been compared with soil application. In those cases where comparisons have been made foliar applied nutrients generally yield a greater response per unit of fertilizer applied.

Because of the relative ease with which phosphorus is fixed by the soil (57) it is possible that application of phosphorus to the foliage can be beneficial under conditions of retarded growth resulting from temporary phosphorus deficiency on cold soils (2). Although response to foliar applied nutrients is more rapid than to soil applications, the effects are not as lasting (20, 40). Thus it is probable that the only conditions under which it would be practical to use foliar sprays of N, P or K are during periods of limited soil moisture, poor soil aeration or low soil temperature, which may inhibit nutrient absorption by roots. Although this practice may temporarily overcome such deficiencies it is unlikely that this method could completely replace soil fertilization.

Because of the large quantities of N, P and K required by plants in comparison to trace elements it would be difficult if not impossible to supply a large percentage of the plant's needs through the foliage. Furthermore, because each of the major elements probably requires different conditions for maximum absorption and because they are seldom all deficient at one time it may not be advisable to apply all three in one application.

Although limited field tests have indicated that under average conditions N, P or K sprays are of little or no practical value, these investigations were conducted with a very limited background of information concerning the factors necessary for foliar absorption to take place. Therefore, before the practice is abandoned, more research should be conducted concerning such factors as the effects of various salts, temperature, light and the physiological condition of the plant, upon absorption. Because of the extreme variation in these factors it is also probable that results obtained in the field at one location would not apply generally.

Results of experiments conducted in southwestern Michigan indicate that incorporation of foliar sprays of urea, a "complete" fertilizer solution or other sprays containing N, P or K did not benefit the yield or quality of cannery tomatoes, sweet corn or cucumbers. Furthermore, no significant increases in nutrient composition could be brought about by nutritional sprays to these crops or to watermelons or muskmelons without danger of injuring the foliage. No significant differences in yield or nutrient content of tomatoes, sweet corn or cucumbers were observed as a result of four different methods of soil application of fertilizer, alone or combined with foliar sprays. No comparisons were made with crops receiving no fertilizer.

Variation in nutrient content of tomato petioles during the season indicates that the physiological condition of the plant and environmental conditions largely determine the amount of the various ions that are absorbed and accumulated by both leaves and roots. Therefore in order to obtain a valid estimate of the average nutrient content of the plant it is advisable to collect tissue samples at several times during the season.

Apparently the amount of injury to plant foliage is a function of the rate of absorption of salts - rapid absorption resulting in accumulation of materials until toxic concentrations result. Greenhouse experiments demonstrated that the chemical composition of a given solution, regardless of concentration, might be more effective in causing injury than the osmotic concentration of the solution. Ammonium ions were found to be particularly injurious to tomato foliage, especially in the presence of Cl^- ions. Although the effect of the Cl^- ion on cell wall permeability has not been established, it is suggested that it increases the permeability of the cell wall to NH_4^+ ions. The factors influencing cell wall permeability, rate of absorption and accumulation, all of which influence injury, have not been established.

Combinations of fungicides with nutritional sprays introduce many additional factors for consideration, foremost of which are the synergistic effects of various combinations. These investigations did not attempt to study the effects of the fertilizer on the fungicidal action of the fungicides but did include observations of the effects of the materials on plants. The precipitation of soluble forms of heavy metals by urea (39), the precipitation of phosphates by Ziram and Bordeaux mixture (104) and the reaction of basic $CuSO_4$ with one of the N, P, K sprays tested illustrate chemical reactions which may interfere with the use of combination sprays. Similarly, synergistic reactions such as occurred when Manzate and a fertilizer solution consisting of $(NH_4)_2HPO_4$, KNO_3 and KCl were combined might limit the use of certain combinations. Although a single application of certain sprays may fail to produce effects, repeated applications might accentuate their action.

The increase in fresh weight from the use of nutrient sprays on tomatoes indicated that nutrients applied in the proper proportions could be used to fertilize greenhouse or cold frame-grown transplants. Because of the ease with which the operation can be performed and the rapidity with which it acts this method could be used to control the nutrient level of such plants.

It is concluded that with the present state of knowledge there is no basis for making specific recommendations for spraying N, P or K on the foliage of vegetable crops as a means of fulfilling their fertilizer requirements or for supplementing an adequate soil supply of nutrients. Any sprays, particularly fertilizer-insecticide-fungicide combinations, should be carefully tested under varied conditions prior to their use on crops in the field or in the greenhouse.

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