Electroculture of Tomato Plants in a Commercial Hydroponics Greenhouse

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ABSTRACT: An experiment was conducted to evaluate the effects of air ion treatment on tomato plants (Lycopersicon esculentum P. Miller) in terms of: (1) growth and health; (2) fruit yield and quality; and (3) economic factors. The plants were grown by a commercial greenhouse(G.H.) grower employing soilless culture techniques. An air ion generator and emitters were installed in such fashion that 864 plants were exposed to a high negative air ion density flux, while 576 plants grew in an area which received relatively few ions. Normal operational procedures, with certain modifications, were employed for plant culture, feed/irrigation, and environmental control.

Plants responded vigouously to air ion stimulation, which equated to shortening of the seeding-to-harvest time period by two weeks as measured by vine growth, main stem height, time to blossoming, fruit set, and fruit yield. Throughout the first four-month growth period plant growth was good and no serious physiological disorders nor insect damage were observed. During the sixth harvest week a virus infection appeared in both control ànd ion-treated plants, but was not of sufficient severity to ruin the experimnent. Foliage and fruit samples were subjected to laboratory analyses. In general, the stimulated plants contained higher percentages of mineral elements than those of the controls. Fruit from ion-treated plants has more ascorbic and citric acid than that from control plants. Although there were no wide differences in fruit texture or flavor, a taste panel verdict indicated that fruit from the stimulated plants tasted better. An unexpected benefit was marked decrease in white fly infestation. All these factors combined with the low cost of air-ion treatment suggest that this modality öffers potential for greenhouse cultivation of garden crops.

INTRODUCTION

THE OBSERVATION THAT atmospheric electricity occurs not only during stormy weather, but in fine weather as well (Lemmonier, 1752) very quickly led natural philosophers to speculate that this constantly prevailing source of energy might influence plant growth. Father Giambatista Beccaria of the University of Turin (1775) stated that, "It appears manifest that nature makes extensive use of atmospheric electricity for promoting vegetation". This putative relationship was independently conceived and explored by Bertholon (1783), Gardini (1782), and Ingenhousz (1788).

The discovery of air ions by Elster and Geitel (1899) and by Thomson (1898) made experiments on the biological effects of atmospheric electricity more comprehensible and ultimately led to the development of suitable methods for their production and quantitation. In 1904 Lemström reported that an electrical discharge from metallic points placed above seedlings produced a measurable stimulation of growth, and this observation was confirmed three years later by Gassner (1907). Blackman and Legg (1924) conducted a long series of experiments on single plants in the laboratory, on plants in pot culture, and on field crops exposed to ion-producing high-voltage, low-amperage electrical discharges. They obtained significant increases in growth and dry weight at harvest. Sidaway (1975) has reviewed the full history of what came to be called "electroculture." His own work has been concerned with the influence of electrostatic fields on seed germination (1967) and the influence of electrostatic fields on plant respiration (1968).

Recently, Winton *et al.* (unpublished data) at Oklahoma State University experimented by exposing green bush beans to a relatively constant DC current of 12 kV delivered 80 cm above the plant tops and providing a relatively constant DC current density of 7-20 picoamperes/plant, and observed a 61% increase in crop weight. A similar application of AC current produced an 85% increase in crop weight. In 1977 Pohl reviewed past work in electroculture and summarized all the recent research. He concluded, "Electroculture, the practice of applying strong electric fields or other sources of small air ions to growing plants, has potential to markedly increase crop production and to speed crop growth". Subsequently, Pohl and Todd (1981) applied these conclusions under greenhouse conditions, They found that a mild current of air ions (4 pA/cm^2) is capable of stimulating bean crop growth and the earlier blossoming and increased growth of the Persion violet and the geranium. Since the period of growth required for the plants to reach marketable maturity was shortened by some two weeks, the authors consider that electroculture may well have practical application.

Murr (1964, 1965a, 1965b, 1966a, 1966b, 1966c) has studied intensively the biophysics of plant growth in electrostatic fields under conditions producing either physiological stimulation or plant damage. During his work with the yellow bush bean and sweet corn he found that increased rates of growth occurred with applied electric fields below 60 kV/m and 100 kV/m, respectively. Above these levels growth rates were decreased. When orchard grass seedlings were exposed to relatively high electric field strength, the plants displayed tip damage and biochemical analyses indicated that the metalloenzyme content of the tissue was altered.

In the course of studies of small air ion action on net blotch disease of barley, Elkiey *et al.* (1977) noted that barley plants exposed to positive ions exhibited significant increases in height and dry weight. Earlier, Maw (1967) had observed growth stimulation of garden cress treated with positive or negative ions.

Bachman *et al.* (1971) experimented with electirc field effects on some 30 varieties of plants. With field strengths of $50<100$ kV/m, a sizzling noise developed and the odor of ozone was detected. The wax bean proved to be exquisitely sensitive to electric field conditions and grew faster than controls (and all other plants tested) under fields of 100-300 kV/m. Subsequently, extensive experiments were conducted with barley plants, with monitoring of air ion production, corona current, and the presence of O_3. Electric field strengths of $<$ 200 kV/m stimulated growth. In a range of electric fields that included those occurring in nature, they found that sufficient corona current developed to produce O_3 and ions. Bachman and Reichmanis (1973) continued experiments with barley plants and concluded that growth is retarded by electric fields $>$ 200 kV/m, while below this level it is enhanced. Growth stimulation is greater at 50 kV/m than at 150 kV/m. Further, the air surrounding the stimulated plants when vented into another chamber enhanced the growth of plants contained therein. They deduced that the growth-enhancing factor is a byproduct of corona and that it develops at relatively low field strength. Growth retardation occuring at higher field strength is associated with current flow from apex to base of the plant--a phenomenon reported earlier by Cholodny and Sankewitsch (1937) and by Lund *et al.* (1947). The mechanisms of electrostatic field actions suggested by Bachman and Reichmanis support the hypotheses espoused by the 18th century philosophers that atmospheric electricity, even in fine weather, acts to promote the growth of plants.

Zhurbitskii (1958) and Zhurbitskii and Shidlovskaya (1967) studied the influence of electrical conditions on the uptake of ions in solution by plants and found that potential gradients equivalent to those prevailing in nature can affect the absorption and incorporation of heavy metal ions. Exposure to artificially increased densities of small air ions enhanced these reactions. Similar results have been reported by Murr (1963, 1964, 1966), by Kotaka *et al.* (1965a) and by Krueger *et al.* (1964). It is significant that an environment in which plants are protected from atmospheric electricity inhibits some of their essential physiological processes and interferes with growth and development (Zhurbitskii 1969; Krueger *et al.* 1965).

Our own experience in this field began in 1960 at the University of California, where we developed facilities permitting exposure of plants to small air ions in a controlled microenvironment (Krueger *et al.*, 1962). For the most part, our subjects were seedlings of oats (*Avena sativa*) and barley (*Hordeum vulgaris*) grown in chemically defined media. We found that seedlings treated with unipolar ionized atmospheres of either charge produced statistically significant stimulation of growth as measured by mean stem length, integral elongation, and dry weight. The extent of growth increase was roughly proportional to the atmospheric ion density and this in turn determined the magnitude of current flow to ground. The minimal current measured in a ground circuit and capable of producing a measurable difference in growth was 4.3-4.6 x 10^{-13} A/plant (Krueger *et. al.*, 1962). Reduction in the air ion content of the air resulted in retardation of growth and loss of turgor (Krueger *et al.*, 1965). The major biochemical changes accompanying the action of air ions on plants were found to be: (1) increase in rate of growth and dry weight; (2) increase in production of cytochrome C and other Fe-containing enzymes; (3) increase in Fe uptake; (4) shift in the distribution of Fe between chloroplasts and the rest of the cell; (5) shift in the rate of dark-light shrinking and swelling of isolated chloroplasts; (6) stimulation of ATP metabolism of isolated chloroplasts; (7) increase in oxygen consumption; (8) increase in RNAase activity of leaves (Krueger *et al.*, 1963; Kotaka *et al.*, 1965; Krueger *et al.* 1964; Kotaka *et al.*, 1968, Kotaka *et al.*, 1965, Kotaka and Krueger, 1972).

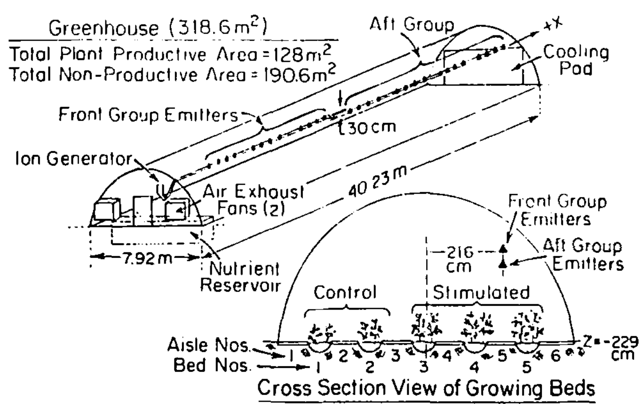

Fig. 1. Longitudinal and cross-section views of the greenhouse. The air-ion emitter installation and the location of the air-ion-treated and control plants are shown.

With this background, we undertook to determine whether the growth stimulation observed under laboratory conditions could be duplicated with a market crop grown in a hydroponics (soilless culture) greenhouse. This experiment was conducted during the period December 1974-July 1975.

MATERIALS AND METHODS

Seedling House (SH)

This structure, 9.6m by 3.4 m and 2.2m high, consisted of ribs and purlins covered with corrugated plastic panels. Exhaust fans at one end provided air circulation, and an automatic heating and cooling unit kept the maximum daytime temperature at ca 27°C and the minimum nighttime temperature above ca 21°C. The air ionization system utilized a high-voltage power supply connected to four emitters (needles) spaced 61 cm apart in a square pattern and suspended 56 cm above the trays which were to be exposed to air ions. It was operational 24 hr. a day. These trays and the emitters above them were located 2 m downstream from the trays holding control seeds and seedlings.

Experimental Plants

Seeds of the indeterminate variety of tomato (*Lycopersicon esculentum* P. Miller), cv tropic VFST, were seeded in moistened pellets and set in shallow plastic trays to germinate. Sixty percent of the pellets were placed beneath the air ion emitters in the seedling house and 49% in the control section. All irrigation, feedings, and environmental control procedures were performed according to the grower's normal operational standards. Treated and control seeds germinated 5 to 6 days after seeding. All the seedlings were left in the seedling house for 16 days before transplanting into the greenhouse, where they were divided randomly into two groups: 864 plants in beds 3, 4 and 5, and 576 in beds 1 and 2. Ion flux density was greatest in the area of beds 3, 4 and 5 (treated plants) and least in that of beds 1 and 2 (control plants). This point is considered in "Discussion".

Structural Design of the Greenhouse

The GH in which the stimulated and control tomato seedlings were transplanted is shown in Fig. 1. Essentially, the GH configuration shown is commonly described as a quonset (kamaboko) house. The primary structure consists of a series of ribs (bulkheads made from assembled plastic pipes with metal pipes as intercostals[purlins]) and roof truss members. The entire structure is covered with fiberglass-reinforced plastic panels. Cutouts are provided at the gable ends for exhaust cooling fans, doors, and cooling pad panels. Secondary structures of steel pipes are installed internally to support the natural gas heater/fan unit and the overhead air distribution duct and also for the necessary wire cables to support the tomato vine/fruit loads. The GH is 40.23 m long and 7.92 m wide, and provides a total productive area of 125 m^2. A covered below-ground level reservoir to contain the nutrient solution and pump/valve assembly is located just inside the entrance door of the GH. Its capacity is 4160 liters. The remaining floor area consists of concrete perimeter walkways, working aisleways, and five double-row planting beds, which accommodate a total of 1440 tomato plants. The beds are sunk below the aisleways and are protected from the earth with plastic liners or barriers. Inert gravel is used to fill the beds and functions as plant root support medium. The beds are periodically flooded and drained during the day with nutrient solution to provide the plant food needs and plant root aeration, The minimal night-time temperature during the experiment was 15°C and the maximal daytime temperature was 25°C.

Air Ion Generators

Negative air ions in this experiment were produced by a Klykon model 130/E109 generator with emitters positioned as indicated in Figure 1. The line of 28 emitters was located directly above aisle 5 between beds 4 and 5. Since the plants in the aft section were 30 cm closer to the emitters than those in the front section, they received a somewhat higher dosage of ions. It should be noted that the placement of emitters relative to the growing beds did not provide an ideal test of air ion effects. As is evident in Figure 1, the control beds 1 and 2 were not completely protected against ion drift from the emitters located above beds 4 and 5. The longitudinal flow of air minimized lateral dispersion, but did not entirely prevent it. At either end of the greenhouse the longitudinal flow averaged 175 ft/min. In the central area the flow from inlet to exhaust was ca. 90 ft/min.

Air ion flux density at various levels of the greenhouse was measured with a target probe and a Keithley electrometer, model 610B. The air ion flux density 20 cm above the growing beds ranged from 8-20 x 10^3 negative ions cm^{-2} in the aft ion-treated area and 6-9 x 10^3 negative ions cm^{-2} in the forward ion-treated area. Corresponding values in both the aft and forward control zones were 5 - 7 x 10^2 negative ion cm^{-2}.

The ion generating system went into operation 24 hrs a day three days after the seedlings were transplanted. Thirty days after transplant, operation was limited to daylight hours. As noted later, there was a brief period of deactivation 100 days after transplanting.

Since as little as 40 ppHM of 0_3 is harmful to tomato plants (Reinert *et al.*, 1972) and corona discharge type ion generators are liable to produce 0_3, we wanted to be sure that the injury threshold was not exceeded. The certified, exceedingly small output of 0_3 by the generator-emitter system employed and the enormous dilution factor imposed by the air exhaust system combined to exclude 0_3 as an element in the present experiment.

Plant Culture and Maintenance

The grower's standard operational and environmental control procedures were followed except for nutrient adjustment and changes in leaf pruning and pollination necessitated by air-ion-induced effects to be described under "Results." For this winter/spring crop during the plant maturing phase and through the immature green phase of the first fruit cluster, the nutrient formulation shown in Table 1 was followed.

Table 1. The elemental content of the basic nutrient formula. This solution was monitored every two days with a conductivity meter and a pH meter.

Element	N	P	K	Ca	Mg	S	Fe	Mn	B	Zn	Cu
ppm	124	99	266	64	17	87	1.32	0.64	0.3	0.38	0.08

During the course of fruit maturation from immature green through mature green and color blush, nutrient concentration imbalance became a frequent occurrence. Accordingly, except for trace elements, a two-step increase (20% per step) in major elements was effected at each nutrient change period, i.e. every three weeks. Visual observation of possible adverse effects stemming from nutrient imbalance was made three times per week. No other serious deficiency or toxic signs were noted except for phosphorus deficiency seen in plants located near the cooling pads. This, coupled with chill, caused some 50 plants to be discolored and stunted at the growing portion. Appropriate changes in temperature and nutrient formula brought about normal new growth within a few weeks. Fruit and petiole samples for analysis were obtained shortly after the early nutrient changes.

Location and Weather

The hydroponics installation used in this experiment is located a few miles northeast of Gilroy, California. The weather pattern for the period involved is summarized in Table 2.

Table 2. Summary of weather data for period of experiment.

Month	Temperature (C) Averages High	Low	Max	Min	Rainfall No. of Days	Total (cm)	Overcast Days 80% Cover during daylight hrs	Remarks
Jan	16.3	1.0	21.7	-5.0	2	0.86	9	Note 3
Feb	16.4	4.7	23.9	-1.7	10	13.31	15	Note 3
Mar	17.2	5.4	25.0	0.0	9	15.40	17	Note 4
Apr	18.9	4.6	26.1	1.1	5	4.50	10	Note 3
May	26.5	17.8	37.8	3.3	0	0.0	2	Note 3
Jun	28.0	19.5	36.1	6.7	0	0.0	1	Note 3

Note: 1) Barometric pressure ranged from a high of 772.2 mm Hg to a low of 750.1 mm.
2) Data source: National Climatic Center, U.S. Dept. of Commerce.
3) No unusual storms.
4) Gusty winds: 25 knots during latter part of month, occurring between 1000 and 1400 hours P.S.T.

RESULTS

After 18 days in the seedling house the air-ion stimulated tomato seedlings were 50-75% taller than the controls and had 1-2 more sets of true leaves.

During the first 30 days after transplanting into the greenhouse, the seedlings in the treated area were stimulated 24 hr. per day. No height or growth differences were noted between the stimulated and control plants, except that microbuds formed on the 20th day in the stimulated plants and on the 28th day in the controls. Blossoms appeared on the 29th day in the ion-treated plants. On the 30th day in the greenhouse we decided to stimulate only during the daylight hours (0700-1900) to allow for a rest period during the night. Several days later a marked elongation of the stems was noted in both treated and control plants. However, the stimulated plants exhibited a stem growth rate substantially greater than that of the controls by the end of the 41st day (Fig. 2). This was equivalent to "plant earliness" growth of 20 days over that of controls. Forty-one days after transplant the growth rates for the stimulated and control plants levelled off and remained constant with respect to each other. However, the residual "earliness" difference in growth rate remained about the same until 120 days after transplanting. Since the tomato plants were grown as single-vine plants, integral elongation measurement

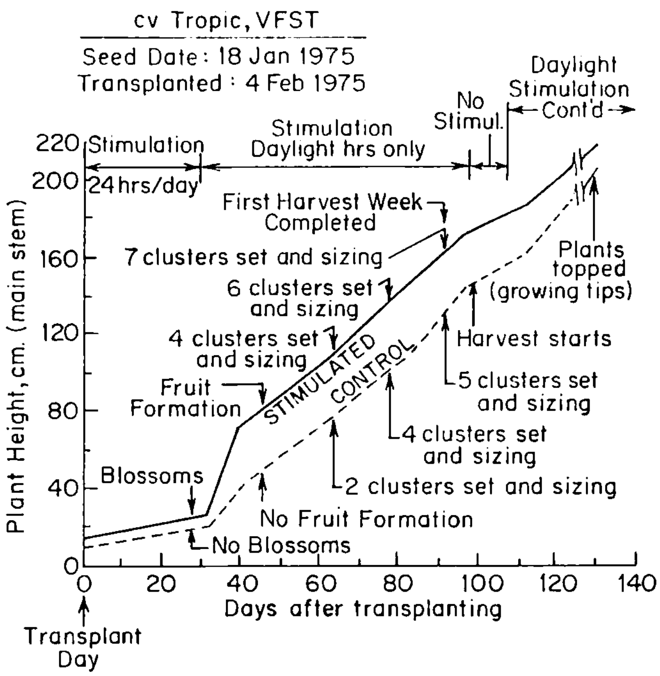

Fig. 2. Plant growth rate of control and air-ion-treated tomato plants. The ordinate indicates average main stem length in centimeters. The abscissa lists the days after transplanting. Major events characterizing the air-ion-treated plants and controls are entered.

was not possible. Consequently, in Fig. 2 only the main stem average rate of growth is shown as a function of days from transplanting. Notes have been entered in Fig. 2 to key certain growth events.

Visual inspection was on a continuing basis for plant responses and physical appearance. The stimulated plants in general had thinner stems, smaller leaves, less dense overall foliage cover and had two or three more flower-fruit clusters than the controls for equal stem height. The labor required for plant leaf pruning was much less for the ion-treated plants than for the controls because of the denser foliage in the latter. On the other hand, less effort was expended on pollination of the controls because the ion-stimulated plants had more flower clusters per plant. These differences balanced one another. Harvesting, sizing, grading, and packaging of mature fruit took place three times per week.

Ninety-seven days after transplanting the growth rate decreased for the stimulated plants and was only slightly reduced for the controls. This phase coincided approximately with the brief period when air-ion treatment was interrupted, as noted below, and produced no ill effect on flowers, fruit growth, or on maturation of tomatoes. Virus desease was detected in control and stimulated plants during the sixth week of harvest and caused a reduction of fruit yield. Diseased plants were removed at a rate of 3% per week of the total plant population, producing a total loss of 25% in the treated group and 10% in the controls. The collecting of data for plant performance in terms of fruit yield and quality was terminated 152 days after transplanting because of the excessive plant deterioration and losses to virus infection.

Harvest of fruit from air-ion treated plants began 104 days after seeding (86 days after transplanting) and proceeded more rapidly than did harvest among the controls. Figure 3 depicts the yield rate per plant as a function of harvest weeks for stimulated and control plants. Figure 4 displays the cumulative fruit yield per unit of greenhouse area. Because of the higher incidence of virus infection in the ion-treated group the yield curves begin to converge at the ninth week. Figure 5 is a plot

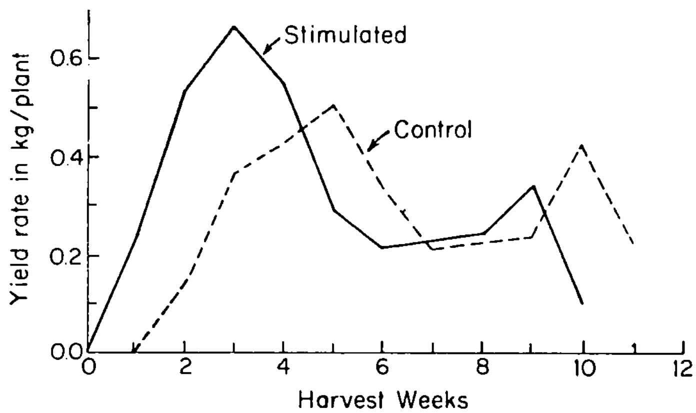

Fig. 3. Tomato plant yield for air-ion-treated and control plants plotted as yield rate against harvest weeks.

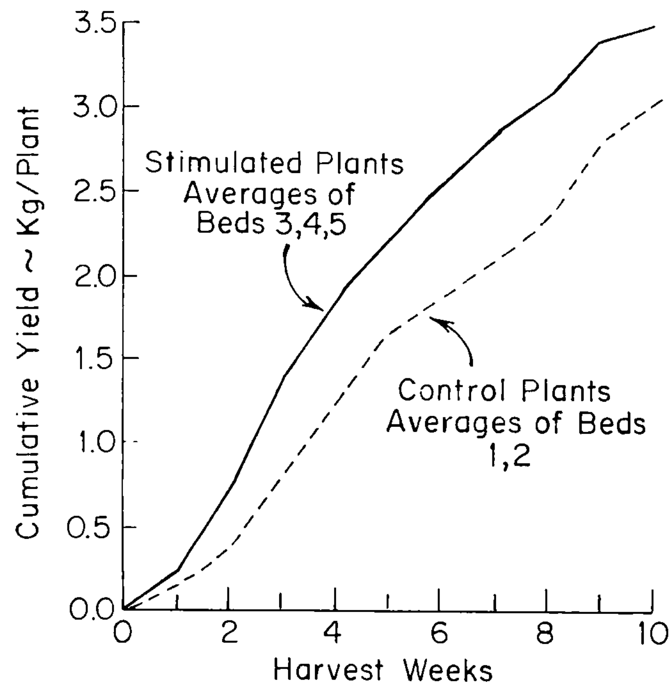

Fig. 4. Fruit yield as a function of greenhouse unit area.

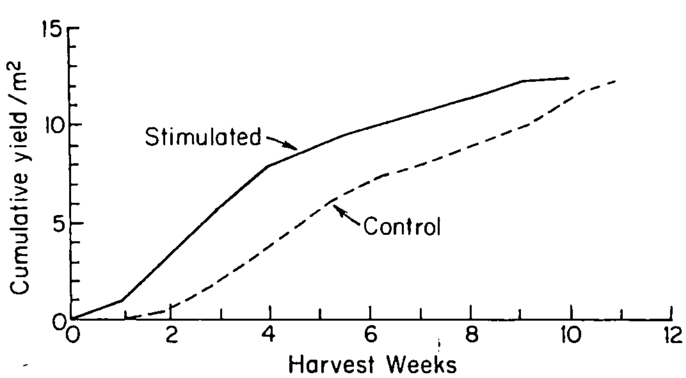

Fig. 5. Cumulative fruit yield per plant for controls and ion-treated plants plotted against harvest weeks.

TABLE 3. Analyses of fruit composition and petiole composition. The fruit composition data represent averages of analyses conducted by the University of California, Davis, and Goldsmith Seeds, Inc. The petiole composition figures refer to dry weight basis as reported by OARDC (Ohio State University), Wooster, Ohio.

Analyses - Fruit Composition (Averages)						
Ripe Fruit from	pH	EC (ppm)	Brix (°)	Citric acid (%)	Ascorbic acid (mg/100g)	Flavor
Control	4.42	2300	5.00	0.34	7.5	Good
Stimulated	4.40	1725	5.18	0.36	11.1	Better

Analyses - Petiole Composition (dry wt basis)	%							ppm								
Petiole	N	P	K	Ca	Mg	Na	Si	Mn	Fe	Cu	B	Zn	Mo	Sr	Ba	Al
Control	1.75	0.93	6.36	1.30	0.38	0.11	0.10	69	99	8	26	26	1.11	64	21	59
Stimulated	1.80	1.11	6.02	1.58	0.55	0.11	0.10	86	110	11	27	36	2.97	65	26	53

of the average cumulative yield/plant for controls and treated plants against harvest weeks.

Independent analyses of fruit and plant (petiole) were conducted on samples taken during the fourth harvest week and the results are displayed in Table 3. These data indicate the air-ion treatment improved the quality of the mature fruit. General observations of differences between ion-stimulated and control plants are summarized in Table 4.

DISCUSSION

During the past three decades through the impact of technological and horticultural breeding advances, the greenhouse production of vegetables, flowers, and bedding plants has become a dynamic and viable industry in the United States. Although the United States lagged behind Europe in terms of greenhouse acreage, the steady growth of the industry is beginning to close this gap, primarily because of increasing demands for high-quality fresh vegetables and flowers at reasonable cost. In general, the greatest concentration of greenhouses in the U.S. is located in the Eastern zone, notably in the state of Ohio. However, other states in the South and mid-Southwest are expanding their facilities. During the last few years the industry in the Pacific states has begun to show remarkable growth, especially in the production of greenhouse tomatoes and European-type cucumbers.

Although the industry has been on an up-trend, the impact of recent crises in availability of energy, escalating prices for fuel, material and supplies, and for labor have imposed a sereve constraint upon plant expansion and facilities. These factors have moved commercial growers in the United States to look for the implementation of technological and horticultural advances that would provide them with increased production and profits within the existing facilities. One potential element in the area of technological advances may well be the application of air-ion treatment.

Despite the fact that as long as 200 years ago atmospheric electricity was suspected of influencing plant growth, the requirements for critical investigation could not be met until 1899 when air ions were discovered. Since then, wide-ranging interest has developed in a whole spectrum of air-ion effects on living forms. The literature contains many accounts of experiments in which air-ion enriched environments have been used to treat diseases, e.g. asthma and weather-induced syndromes such as the sharav illness of Isreal. This phase of air-ion research has not been implemented in conventional medical practice, largely because of failure to meet the requirements of satisfactory experimental design and neglect of the placebo effect. Studies of general biological effects using bacteria, protozoa, higher plants, insects, and higher animals have been more productive, to the point where it now is possible to state that air ions *are* biologically active. As noted in the introduction of this paper, there even exists a fair amount of information regarding the mechanism of air-ion stimulation of plant growth.

Our goal in the present study was to determine whether the air-ion enhancement of plant growth, so readily demonstrable in the laboratory, occurs on a large scale under "practical" conditions, The experiments were conducted with tomato plants in a California hydroponic greenhouse facility where tomatoes and cucumbers are the primary vegetable crops. Hydroponics (soilless culture) was chosen as a first-choice test bed program because of it flexibility in the control of such variables as nutrient formulation and concentration, extent of irrigation, and environmental factors.

Our experimental design included observations for air-ion induction of (a) growth stimulation, (b) acceleration of fruit

TABLE 4. Observations comparing the results of negative-air-ion treatment of the spring tomato plant crop with a control (untreated) crop.

1. PLANT CHARACTERISTICS	REMARKS
a. Stem height growth	Earlier by two weeks
b. Stem diameter, averages (mature plants)	Smaller; 1.6 cm vs 2.1 cm for control
c. Leaf size (area), averages (mature plants)	Smaller by 60% to 75%
d. Cluster internode averages	Closer; 18 cm vs 25 cm for control
e. Number of flowers per cluster, averages	No significant differences
f. Petiole analysis	See Table 3
2. BUD, BLOSSOM & FRUIT FORMATION	
a. Buds and blossoming	Earlier by about two weeks
b. Fruit set	Earlier by about two weeks
c. Fruit ripening	Earlier by about 10 days
d. Fruit conformation and quality	Better by 10% to 15% for Grade 1
e. Fruit size	More of larger sizes (4x5s & 5x5s)
f. Fruit composition and flavor	See Table 1
3. FRUIT YIELD RATE PER PLANT	
a. Yield rate per week	Greater by 50% in first 3 weeks
b. Cumulative yield rate	Greater by 27% at end of 6 weeks
c. Spring crop yield	Equalled the previous good summer crop (untreated)

4. NUTRIENTS
   a. More adjustments required for N, P, K and Ca since a closed loop (nutrient recycling) method was employed for this experiment.

5. UNCERTAINTIES
   a. Optimum air-ion dosage level requirement for other cultivars or at different stages of plant maturity.
   b. Optimum air-ion dosage duration and/or frequency of application.
   c. Effects of air ions, of either polarity, on plant disorders due to viruses and fungi, and on flying or crawling insects.
   d. Apparent premature senescence of plants. Possibly due to bioelectrical effects described in introduction.

maturation/ripening, (c) increased crop yield and (d) improvement of fruit composition, We recognized that in such a preliminary experiment it would not be feasible to conduct a definitive test employing the control conditions one would impose in the laboratory. Ideally, an experiment of this sort should utilize two sections of the same greenhouse, one housing the treated plants, and the other the controls, completely isolated from the artificially ion-enhanced atmosphere. For practical reasons, we were not able to install a Faraday cage to pervent ions from reaching controls. As a compromise, we made use of the fact that air-ion density falls off rapidly with distance from the ion source. The emitters were so positioned along the length of the greenhouse that beds 3, 4 and 5 were closest to them and could be considered to present an ion-treated area (Fig. 1). Beds 1 and 2 were far enough away to serve as controls although they undoubtedly received a low dosage of ions. Consequently, in the absence of a completely untreated set of controls, any differences in biological effects observed during this experiment could be ascribed to differences in air-ion dosage. On the basis of the averages of the ion flux densities (number of ions/cm^2/sec) at plant level in the three different areas of the experiment, ion-treated plants in the aft section received ca 17 times the dosage of plants in the control areas, while ion-treated plants in the forward section were exposed to ca 13 times as many ion as the control plants.

It can be argued that the plant responses observed on our experiments depend on differences in the imposed electrical fields. Clearly, the control plants were exposed to lower electrostatic fields than the two groups on ion-treated plants. However, the work of Bachman and Reichmanis (1971) and our own experiments (Krueger *et al.*, 1978) demonstrate that air ions are the primary element in conveying the small electrical currents to plants that result in increased rate of growth. In our experiments, conducted in very low electrostatic fields, no growth enhancement occurred until air ions were added to the ambient air. Bachman and Reichmanis found that increases in plant growth, in the absence of added air ions, depended upon the intensification of relatively low electrical fields at the pointed ends and fine hairs of plants to such a degree that corona developed and air ions were produced. The electrical currents required to stimulate growth are quite small: 6-10 pA/plant in our early studies (Krueger, *et. al.*, 1962), 10 pA/plant in more recent ones, and 10 pA in Blackman and Legg's (1924) series. Pohl and Todd (1981) reported a current of 4 pA/cm^2 at plant level to be effective in expediting the growth and blossoming of geraniums and Persian violets.

The goal of the experiment recorded here was to evaluate the application of electroculture in the production of tomatoes in a hydroponics greenhouse. The generally favorable effects observed lead to the conclusion that the air ion enriched environment was responsible for:

1. Earlier appearance of buds and fruit by two weeks.
2. Earlier fruit ripening by 10 days.
3. Cumulative fruit yield rate per plant greater by 27% at the end of six weeks.
4. Superior fruit conformation and quality by 10%-15% for Grade 1.
5. Improved fruit size.
6. Improved fruit flavor and compostion.

Since the costs of installing air ion generators are modest, their energy requirements are minimal, and no detrimental effects of negative air ions on the personnel have been observed, this procedure appears to be a useful addition to greenhouse technology.

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