EFFECT OF SOIL-INJECTED ETHYLENE ON SUGARBEET (BETA
VULGARIS L.) YIELD PARAMETERS

by

Leonard John Franci

A Thesis Submitted to the Faculty of the

DEPARTMENT OF PLANT SCIENCES

In Partial Fulfillment of the Requirements
For the Degree of

MASTER OF SCIENCE

WITH A MAJOR IN AGRONOMY AND PLANT GENETICS

In the Graduate College

THE UNIVERSITY OF ARIZONA

STATEMENT BY AUTHOR

This thesis has been submitted in partial fulfillment of requirements for an advanced degree at The University of Arizona and is deposited in the University Library to be made available to borrowers under rules of the Library.

Brief quotations from this thesis are allowable without special permission, provided that accurate acknowledgment of source is made. Requests for permission for extended quotation from or reproduction of this manuscript in whole or in part may be granted by the head of the major department or the Dean of the Graduate College when in his judgment the proposed use of the material is in the interests of scholarship. In all other instances, however, permission must be obtained from the author.

SIGNED;

Leonard J. Farnel

APPROVAL BY THESIS DIRECTOR

This thesis has been approved on the date shown below:

Robert E. Dennis

ROBERT E. DENNIS
Professor of Agronomy

December 8, 1975

Date

ACKNOWLEDGMENTS

I would like to express my sincere appreciation to all the persons who helped me complete the requirements for my Master of Science degree, especially my advisor, Dr. Robert E. Dennis, whose unselfish assistance guided my path of study. I am grateful to other members of my committee, Drs. William R. Kneebone, Dwayne R. Buxton, and Arthur H. Freytag, whose suggestions and assistance proved invaluable to the conduct and preparation of this thesis.

I am also grateful to Sherill Thomson, David Parsons, and John Nelson for their assistance throughout the course of this study.

I would like to thank all the professors and administrators in the College of Agriculture not mentioned who shared their time and knowledge with me during my studies at The University of Arizona. I would also like to thank the members of the Arizona Sugarbeet Growers Association, Amstar-Spreckels Company of Chandler, Arizona, Great Western Sugar Company of Longmont, Colorado, and Air Products and Chemicals Incorporated of Allentown, Pennsylvania, who provided the cooperation and monetary assistance which made this study possible.

I am grateful to my roommate, Gregory Brisbane, for his generosity.

TABLE OF CONTENTS

	Page
LIST OF TABLES	v
LIST OF ILLUSTRATIONS	vi
ABSTRACT	vii
INTRODUCTION	1
REVIEW OF LITERATURE	3
Nature and History of Ethylene	3
Effect of Ethylene on Plant Growth	5
Effect of Ethylene on Membrane Permeability	6
Effect of Ethylene on Roots	7
Occurrence of Ethylene in Soil	9
Beneficial Effects of Ethylene	10
Effects of Ethephon on Plant Growth	11
MATERIALS AND METHODS	13
Experiment I	13
Experiment II	17
Experiment III	19
Experiment IV	20
Climatology for the Experiments	24
RESULTS AND DISCUSSION	25
Experiment I	25
Experiment II	32
Experiment III	37
Combined Analysis Experiments I, II, and III	41
Experiment IV	43
SUMMARY AND CONCLUSION	51
REFERENCES	54

LIST OF TABLES

Table	Page
1. Chemical analyses of soil from experimental fields near Kansas Settlement	28
2. Nitrate nitrogen in the upper 15 cm of soil from experimental fields near Kansas Settlement	29
3. Sugarbeet petiole nitrate nitrogen of experiments near Kansas Settlement	30
4. Sugarbeet root weight, per cent sugar, and sugar yield of experiments in the Kansas Settlement area	31
5. Chemical analyses of soil from experimental fields near Sacaton	36
6. Sugarbeet root weight, per cent sugar, and sugar yield of experiments in the Sacaton area	36
7. Chemical analysis of soil from experimental field near Chandler	40
8. Sugarbeet root weight, per cent sugar, and sugar yield of experiment near Chandler . . .	41
9. Mean sugarbeet root weight, per cent sugar, and sugar yield from three experiments in central and southeastern Arizona	42
10. Chemical analysis of soil used in potted experiment at Tucson	47
11. Effect of ethylene on sugarbeet seedling emergence	47
12. Effect of ethylene injected into the soil on seedling weight of sugarbeets grown in pots	49

LIST OF ILLUSTRATIONS

Figure	Page
1. Photo showing mounting of cylinder, pressure regulator, and shank used to inject ethylene into the soil	14
2. Diagram showing the plot layout used in the first experiment	16
3. Photo showing mechanical harvester used for field experiments	18
4. Photo showing arrangement of test pots in Experiment IV	21
5. Daily maximum and minimum air temperatures at Willcox from May 15 to November 15, 1974	26
6. Precipitation at Willcox from May 15 to November 15, 1974	27
7. Daily maximum and minimum air temperatures at Sacaton from March 15 to June 15, 1975	33
8. Precipitation at Sacaton from April 1 to June 15, 1975	35
9. Daily maximum and minimum air temperatures at Chandler from March 15 to July 31, 1975	38
10. Precipitation at Chandler from March 15 to July 31, 1975	39
11. Daily maximum and minimum air temperatures at Tucson from April 21 to June 15, 1975	44
12. Daily maximum and minimum relative humidities at Tucson from April 21 to June 15, 1975	46

ABSTRACT

The effect of soil-injected ethylene on the yield components of sugarbeets (Beta vulgaris L.) was investigated over a two-year period in experiments conducted in production fields and at The University of Arizona.

Ethylene was soil injected at 6.2 kg/ha at a depth of 20 cm in three fields of sugarbeets in 1974 and in four fields in 1975. Beets were harvested from rows 1, 5, 10, and 50 (76 cm between row spacing) from the place of application. A general decline in sugar yield with distance from application was noted, but there were no significant differences in any of the yield parameters measured due to high variability.

Ethylene was soil injected and Ethrel was applied to the soil surface as preemergence treatments in a potted experiment. Ethrel was fatal to sugarbeet seedlings, and there were no significant differences among the ethylene treatments in total per cent or speed of emergence. Ethylene was soil injected during the fifth week after planting, but there were no significant differences among seedling fresh or dry weight as a result of these treatments.

Results indicate that soil injection of ethylene can not be recommended at this time as a method for increasing sugar yield of beets in Arizona.

INTRODUCTION

Sugarbeets (Beta vulgaris L.) are an important part of the agricultural industry of Arizona. In 1974, 224,000 metric tons of beets were produced on 4,200 irrigated hectares, with a gross value of over 8 million dollars. Sugarbeets are grown in the low desert valleys of central and western Arizona, and at the higher elevations in southeastern Arizona. In the low desert valleys where winter temperatures are mild, beets are planted in the fall and harvested in the early summer. At higher elevations, beets are planted in the spring and harvested in the fall.

Effects of ethylene on the physiology of higher plants have been intensively studied. Ethylene is known to play a role in abscission, flower formation and sexual expression, epinasty, fruit ripening, and other processes. Much less is known, however, about the effect of exogenous ethylene in soil-plant relationships.

Arthur Freytag, Research Agronomist with Great Western Sugar Company, Longmont, Colorado, is actively studying beneficial effects of soil-injected ethylene on sugarbeet yields. Because he has obtained a positive response and because of the similar climates of Colorado and southeastern Arizona, a study was initiated near Willcox in 1974.

The objective of this study was to determine whether a soil injection of ethylene would enhance the yield of sugarbeets.

REVIEW OF LITERATURE

Nature and History of Ethylene

Ethylene, or ethene according to IUPAC nomenclature, is unique in its role as a plant growth regulator in that it is a gas at normal physiological temperatures. According to Burg (9) ethylene is a natural product of plant metabolism, active in trace amounts. Ethylene is an unsaturated hydrocarbon, the simplest member of the alkene functional group, with a formula of C_2H_4 . It has a boiling point of -104 C (30) and a solubility in water of 130 ppm at 20 C (38).

The phenomenon of defoliation of plants exposed to illuminating gas drew the attention of researchers around the turn of the century (47). The discovery of ethylene as the active agent prompted further research on its effect on plants. Knight and Crocker in 1913 (33) were the first to describe the "triple response" by pea (Pisum sativum L.) seedlings: stunting, swelling, and epinasty. This response has since been used as a bioassay to test for the presence of ethylene. Gane in 1934 (28) was the first to chemically isolate ethylene from gaseous products collected from climacteric apples (Pyrus malus L.), thus proving that ethylene could be produced by plants. With the advent of gas chromatography, Burg and Thimann (14) confirmed ethylene's presence in plant tissue in 1959. Research

related to ethylene's effects on plant physiology increased markedly with the introduction of this technique.

The site of ethylene production in the cell is unknown, but the pathway of chemical reactions is thought to have methionine as a precursor. Lieberman et al. (35) added ^{14}C -methionine to apple slices and obtained a 60% conversion efficiency into ^{14}C -ethylene. Baur and Yang (7) proposed a pathway for ethylene production in vivo that included, in part, methionine $\rightarrow$ keto- γ -methylthiobutyric acid $\rightarrow$ methional $\rightarrow$ ethylene. Abeles (1) reviewed pertinent literature and noted that additional compounds have been suggested as possible precursors to ethylene evolution. These included linolenic acid, beta-alanine, propanol, and ethanol, among others. However, the weight of the evidence seems to support the methionine hypothesis.

Commercially available ethylene is a product of the petroleum industry. Natural gas or petroleum is passed through a high temperature chamber and undergoes pyrolysis (cracking), yielding ethylene and other short chained molecules (43). These end products are purified by fractional distillation.

Ethepon (2-chlorophosphonic acid), or Ethrel, is an ethylene releasing chemical important to agricultural commerce as a fruit ripening agent. Ethylene concentrations in the atmosphere are carefully managed in the post-harvest

physiology of fruit crops, including banana (Musa paradisiaca L.) and citrus (Citrus spp. L.).

Effect of Ethylene on Plant Growth

Ethylene affects plant metabolism throughout the plant's life cycle. Some effects of ethylene include: induction of seed germination, stimulation of abscission, growth retardation, epinasty, stem swelling, stimulation of root hair development, induction of flower formation, modification of sexual expression, induction and acceleration of fruit ripening, and stimulation of adventitious rooting (8, 21, 22, 33, 50, 61, 64, 67).

Meheriuk and Spencer (41) found that ethylene was produced during the first 24 hours in germinating oat (Avena sativa L.) seedlings. Spencer and Olsen (57) observed peaks in endogenous ethylene evolution during germination of castor bean (Ricinus communis L.) seed at 3, 9 to 10, and 14 to 15 days. These peaks corresponded with seedcoat breaking, seedling emergence, and separation of leaves from cotyledons, respectively. Jones (31) reported that an application of ethylene to the isolated barley (Hordeum vulgare L.) aleurone layer accelerated the release of alpha-amylase from aleurone cells, but there was no effect on the total amount of enzyme produced. Goeschl, Rappaport, and Pratt (29) found that elongating pea epicotyls evolved high rates of ethylene when subjected to physical stress.

Exogenous applications of ethylene have been used to increase the germination rate of seeds of wheat (Triticum aestivum L.), lettuce (Lactuca sativa L.), peanuts (Arachis hypogaea L.), subterranean clover (Trifolium subterraneum L.), and aged seeds (3, 6, 25, 59, 60). Ketring and Morgan (32) showed high rates of ethylene evolution in peanut seeds breaking dormancy and a stimulation of germination when 3 ppm of ethylene were applied as pregermination treatments to resting seeds.

Pratt and Goeschl (47) observed that ethylene may contribute to the hormonal mechanism that controls the mobilization of food reserves as germination begins. They noted that accelerative effects to germination occurred when ethylene was applied as a treatment before radicle emergence. Roberts (49) and Stewart, Lieberman, and Kunishi (58) used ethylene in studies of wheat and peas, respectively. They both found that continued exposure to the gas after radicle emergence resulted in inhibitory growth effects.

Effect of Ethylene on Membrane Permeability

Because of conflicting reports, there are still questions about the effect of ethylene on the integrity of membranes. In an early study, Nord and Frank (46) found that exogenous ethylene application increased the permeability of brewer's yeast (Saccharomyces spp. Meyen) cells. However, their result has been disputed by Shaw (53). Lyons

and Pratt (37) used concentrations of ethylene above normal physiological levels with in vitro cauliflower (Brassica oleracea L. cul. botrytis) and rat (Rattus rattus Fischer) mitochondria. They observed that ethylene application made mitochondria swell and inferred that permeability had been increased. However, Mehard and Lyons (40) later demonstrated that mitochondria could be caused to swell by a number of hydrocarbon gasses. Thus, there was a lack of specificity for induced mitochondrial changes.

Abrams and Pratt (4) asserted that ethylene increased cell permeability in excised cantaloupe (Cucumis melo L.) tissue. Burg (10) disagreed and cited his own work (13) to point out that ethylene did not enhance permeability as it affected pea tissue. Sacher (52) studied fruits undergoing climacteric ripening and concluded that changes in cell permeability may be a peculiarity of the ripening process. More recently, Abeles (1) suggested that available evidence indicates that changes in permeability in fruit are the result of, rather than the cause of ripening processes.

Effect of Ethylene on Roots

Several workers at the Boyce Thompson Institute studied ethylene effects on roots in the 1930's. Zimmerman and Hitchcock (67) initiated and stimulated adventitious rooting on stem tissue by exposure to ethylene. They also noted an abundance of root hairs on these adventitious roots.

Denny (21) found by bioassay that the roots of Beta vulgaris evolved ethylene.

Crocker, Hitchcock, and Zimmerman (19) noticed similarities in many plant responses due to the effects of ethylene and auxin. Chadwick and Burg (15) found that indoleacetic acid (IAA) inhibited cell elongation in intact roots. They concluded that this occurred as a result of IAA-dependent ethylene production. However, Andreae et al. (5) studied the kinetics of the inhibited cell elongation response and the promotion of ethylene evolution and concluded that they are independent effects. Thus they assert that there is some doubt concerning the importance of ethylene in mediating root growth inhibition by IAA. Chadwick and Burg (16) disputed the work of Andreae et al. (5) by presenting additional evidence to support their claim of IAA-dependent ethylene production.

Radin and Loomis (48) found that ethylene treatment resulted in an inhibited growth response in radish (Raphanus sativus L.) roots. Chadwick and Burg (15) and Burg and Burg (12) observed that exposure to ethylene led to a radial enlargement of root tissue that largely compensates for the decrease in elongation and which resulted in little net change in fresh weight. The radial enlargement was a result of inhibited cell elongation, not increased cell division.

The induction of radial swelling by ethylene may play a role in the marked increase in root hair formation (2). Since there are more epidermal cells per unit length after exposure to ethylene, there also would be an increase in root hair initials per unit length. Chadwick and Burg (15) also observed the phenomenon of increased root hair formation after ethylene treatment. Burg (10) states that radial expansion in roots and increased root hair formation due to the effect of ethylene may indicate some effect of ethylene on the structure of the cell wall.

Occurrence of Ethylene in Soil

Microorganisms in fermentation cultures and fungi evolve ethylene (20, 45). Smith and Russell (56) showed that ethylene occurs in soils, and accumulates under anaerobic conditions. They inferred no ethylene accumulation under aerobic conditions.

Smith and Restall (55) suggest that ethylene concentrations under anaerobic conditions may inhibit root growth. They found that young barley roots, exposed to ethylene for 3 days, had growth reductions of 50% when exposed to 1 ppm, and 80% at 10 ppm, ethylene. They state that the kind and amount of organic matter, plant roots, and soil wetting and drying are factors affecting the production of ethylene in soil.

Beneficial Effects of Ethylene

Egley and Dale (23) showed that germination of the parasitic witchweed (Striga asiata L., O. Kuntz) can be stimulated by application of ethylene. Witchweed seed germination in the absence of a host plant results in suicidal emergence. The response of this plant to ethylene is now an integral part of the witchweed eradication program (24). These researchers also found that one-half of maximum response occurred between 0.1 and 0.3 ppm ethylene, which is within the range of dose response of other physiological processes reported by Burg (10). Egley and Dale (23) noted that addition of CO₂ inhibited the germination response to ethylene application. Burg and Burg (11) had previously found that CO₂ is a competitive inhibitor of ethylene action.

Smith (54) found that ethylene has fungistatic properties. He observed that germination of sclerotia from Sclerotium rolfsii Sacc. could be inhibited by an airstream containing ethylene or by a still atmosphere which allowed a buildup of native ethylene. Chalutz and DeVay (17) found that an ethylene treatment decreased the thickness of callus formed in sweet potato (Ipomoea batata Lam.) tissue infected with black rot (Ceratocystis fimbriata Ell. and Halst.), but that ethylene did not impart resistance to the pathogen. They recognized that ethylene production in the host-pathogen interaction is probably a response by the host to physical injury caused by the pathogen.

Freytag, Wendt, and Lira (27) obtained increased yield from cotton (Gossypium hirsutum L.), sorghum (Sorghum vulgare Pers.), and sugarbeets (26) when ethylene was injected into the soil. Lira and Freytag (36) found that soybean (Glycine max Merr.) seedlings grown in hydroponic culture and treated with ethylene were taller than controls but had reduced fresh weight of roots and shoots.

Eplee (24) found that ethylene will move through undisturbed soil more than 120 cm horizontally and more than 90 cm below the soil surface to cause witchweed seed germination. He observed that lower rates of ethylene are effective in a light textured soil but higher rates of ethylene are needed to germinate seeds in a heavy textured soil. Freytag (26) found that soil injection of ethylene resulted in concentrations in the soil atmosphere that were above normal (i.e., 0.1 to 8 ppm [56]) for about 8 days. He also detected an above-normal level of ethylene 25 m from the point of soil injection. Nelson (44) found that ethylene injected into soil in pots resulted in an above-normal level of ethylene in the soil atmosphere for about 3 days.

Effects of Ethephon on Plant Growth

Ethephon (2-chloroethylphosphonic acid), or Ethrel, is an ethylene releasing compound (66) that is used commercially to promote accelerated, uniform ripening of

fruits. Release of ethylene from Ethrel was shown to increase with increasing pH (65).

Ethrel foliar applications increased the female expression of flowers (51) of cucumber (Cucumis sativa L.), pumpkin (Cucurbita pepo L.), and muskmelon (Cucumis melo L.); and induced flowering (18) in pineapples (Ananas comosus Merr.). Morgan (42) found that Ethrel hastened abscission of cotton leaves when applied foliarly. Abscission in cotton appears to be a result of a complex interaction of ethylene, auxin, senescence factors, and possibly gibberellins (34).

MATERIALS AND METHODS

Experiment I

Three sugarbeet plantings in the Kansas Settlement area about 30 km south of Willcox, Arizona, were used for the first field experiment. When the experiment was initiated on May 29, 1974, sugarbeet plants were 2 to 3 months old and had a leaf span of 25 to 35 cm. Beets in this test were in single rows 76 cm apart. The soil at these locations was a sandy clay loam.

For treatment applications, a cylinder containing technical grade ethylene was mounted on a tool bar attached to a tractor (Fig. 1). The ethylene was delivered through a gas flow regulator and meter. Plastic hose was used to connect the gas outlet to an anhydrous ammonia shank. The shank was hydraulically forced into the soil in the middle of the furrow so that the point of ethylene emission was about 20 cm below the soil surface.

Ethylene injection was initiated about 15 m from the end of a randomly selected furrow and continued to a point about 15 m from the opposite end of the furrow. Two furrows per field were treated in this manner. The rate of ethylene application (kg/ha) is a function of the weight of ethylene (g/l), the flow rate (l/min), tractor speed (km/hr), and the area treated (m^2 or ha). Calculations for the area covered

Fig. 1. Photo showing mounting of cylinder, pressure regulator, and shank used to inject ethylene into the soil.

by rows adjacent to injection were made as follows:

$$\frac{28.05 \text{ g}}{\text{mole}} \times \frac{\text{mole}}{22.4 \text{ l}} \times \frac{30 \text{ l}}{\text{min}} \times \frac{1.25 \text{ min}}{76 \text{ m}^2} = 0.62 \text{ g/m}^2$$

$$= 6.2 \text{ kg/ha.}$$

Two 30.5 m lengths of row adjacent to each injected furrow were chosen for sampling and harvest. Additional 30.5 m strips, approximately perpendicular to the endpoints of the first selected length of rows, were measured in rows located 3.4, 7.2, and 37.7 m from the injected furrow (Fig. 2). The four distances from injection in each plot correspond to rows 1, 5, 10, and 50, counting from the injected furrow. Assuming equal diffusion of ethylene, rows 1, 5, and 10 were exposed to decreasing ethylene concentrations, while row 50 was considered to be untreated.

Petiole samples were taken from each of the four rows in test plots on June 28, July 25, and August 30, according to the method described by Ulrich (62). Soil samples were taken with an Oakfield probe on the same dates from a location within each of the four rows in the test plots. Soil sampling locations 1 m in diameter were identified and on each sampling date a composite of soil cores was taken from the upper 15 cm. Nitrate nitrogen levels in the petiole and soil samples were determined by the Great Western Sugar Agricultural Research Center, Longmont, Colorado. In addition to this, a soil sample was taken

Fig. 2. Diagram showing the plot layout used in the first experiment.

with an Oakfield probe on the date of ethylene application from a cross section of each field to determine the chemical status of the fields. These three samples were analyzed at the Soil Testing Laboratory, The University of Arizona.

The sugarbeets were first mechanically topped and then dug on November 3 and 4, 1974, using a modified, single-row sugarbeet harvester. Beet weights from each plot were determined with a weighing bin mounted on the harvester (Fig. 3). A subsample of five beets was used from each plot to determine the sugar percentage. These subsamples were analyzed for sugar by Amstar-Spreckels Sugar Company, Chandler, Arizona, and these data were used to calculate the yield of sugar.

Data from each field were statistically analyzed with sources of variance for location of injection within field, distance from injected furrow, location of injection x distance from injected furrow, and an error residual. A combined analysis for the three fields in Experiment I was then done, separating variances for fields, distance from injected furrow, fields x distance from injected furrow, and an error residual.

Experiment II

Three sugarbeet plantings near Sacaton, Arizona, were selected for the second ethylene field experiment. Beets were planted in a clay loam soil in October, 1974, and

Fig. 3. Photo showing mechanical harvester used for field experiments.

at the time of ethylene application the plants had a leaf span of 25 to 35 cm. When the experiment was initiated, soil samples were taken for chemical analysis from a cross section in each of the three fields.

Ethylene was soil injected on March 24, 1975, at approximately the same rate and depth as the first experiment. Plots were the same length, and the rows harvested were the same distance from the place of ethylene application as in the first experiment. Soil and petiole samples were not taken subsequent to the date of ethylene application. At harvest on June 2 and 3, 1975, two subsamples per plot, consisting of five beets each, were taken for sugar analyses. Data were analyzed using the same statistical procedures as in Experiment I.

Experiment III

A sugarbeet planting south of Chandler, Arizona, in a silty clay loam soil, was selected for the third field experiment. Beets had been planted on October 15, 1974, and had a leaf span of 25 to 35 cm when ethylene was applied on March 25, 1975. A representative soil sample was taken for chemical analysis after ethylene was injected into the soil.

Plot design and experimental procedure for the third experiment were similar to that of the previous two experiments. Since this experiment included only one field, yield

and other data were based on four samples. Beets were mechanically harvested on July 22, 1975, with two subsamples per plot, consisting of five beets each, taken for sugar analyses.

Experiment IV

Soil from Field I of the second experiment was used for a study conducted at The University of Arizona Rincon Vista Turfgrass Research Center, Tucson, Arizona. The clay loam soil was thoroughly mixed and then sampled for chemical analysis. Ammonium phosphate (16-20-0) was added to provide the equivalent of 88 kg/ha N and 110 kg/ha P_2O_5 . Fertilizer application rate was based on the surface area of the soil in the pot.

Plastic pots having a volume of 2.8 l and a diameter of 15 cm were used for this experiment. Toilet tissue was placed over the opening in the bottom of each pot and then covered with 2.5 cm of sand. For this experiment, 126 pots were used and each pot was filled with soil to within 2.5 cm of its top. The dry weight of soil and sand in each pot was about 2.4 kg.

A wooden frame measuring 3.0 x 1.5 x 0.3 m was placed on the ground in an open area. Twelve replications of seven treatments were arranged in a randomized, complete block design within this frame. The test pots were surrounded by a single row of border pots (Fig. 4). After the

Fig. 4. Photo showing arrangement of test pots in Experiment IV.

pots were in place, sand was placed between pots to the top of the pots. A 0.95 cm ID plastic tube was inserted into the soil of 36 pots with the end of the tube 8 cm from the bottom of the pot. A thermometer was placed into the soil of a border pot.

Twenty sugarbeet seeds, US H9, were planted in each pot at a depth of 2 cm on April 22, 1975. Each pot received 200 ml of water to initiate imbibition. One day later, a cylinder of technical grade ethylene was connected to three pots per replicated block and ethylene was metered through a flow regulator for 6, 12, and 24 sec at a flow rate of 5 l/min. Thus, the application rate for the gas was 0.5, 1.0, and 2.0 l/pot. Four additional treatments consisted of Ethrel mixed with tap water at 0, 20, 40, and 80 ml/l. Pots in this series received either 500 ml of the appropriate Ethrel solution or 500 ml of water.

Seedlings were considered emerged when the hypocotyl hook was visible. Counts were taken daily from the 5th to the 15th day. Mean day of emergence and total emergence were determined and speed of emergence was analyzed by the method of McGuire (39). Seedlings were thinned to four per pot 23 days after planting. Pots were irrigated with 700 ml tap water at 5-day intervals between April 22 and May 25, a 4-day interval (May 25 to 29), and at 3-day intervals thereafter.

Emergence data and weights of harvested seedlings were statistically analyzed for ethylene treatment effect. Sources in the analyses were replications, treatment, and an error residual.

A second soil injection of ethylene was made to this experiment on the 36th day after planting. Pots receiving this application were those first treated with ethylene gas. Applications rates were similar to those used for the first treatment, but in this instance, a clip was placed on each exposed tube end to prevent escape of ethylene.

Two days after the second ethylene treatment, three more pots per replication were similarly treated with ethylene gas immediately following irrigation. These pots had no previous treatment, having been recently transferred from the border perimeter. Application rates were 3.0, 4.0, and 5.0 l of ethylene per pot. Clips were placed on each exposed tube end after the injection was completed.

Harvest was on June 12, 13, and 14, with four replications taken each day. Plants were carefully depotted and soil was washed away from the roots with water under low pressure. The plants were then placed in the sun until all free moisture had evaporated from their leaf surfaces. Intact plants were sealed in plastic bags and refrigerated until weighing.

Fresh weights of the four plants in each sample were collectively determined. Plant tops were excised from the root at the crown with a razor blade and reweighed. The tops were dried overnight and weighed again.

Climatology for the Experiments

Maximum and minimum temperatures and precipitation data from the weather station nearest the field plots were obtained from the U.S. Department of Commerce (63) for the period during which each field experiment was in progress. A hygrothermograph situated 20 cm above the soil surface in a standard U.S. Weather Bureau shelter and 60 m from the experimental site was used in the fourth experiment.

RESULTS AND DISCUSSION

Experiment I

Climatic data for Experiment I are those from the nearest weather station, Willcox, Arizona. The daily maximum and minimum air temperatures from May 15 to November 15, 1974, are presented in Fig. 5. The maximum air temperature on the date of ethylene application was 34 C. The highest air temperature recorded during the experimental period was 42 C on June 24. The lowest air temperature was 9 C on October 30, near the harvest date. The average maximum and minimum air temperatures during the experiments were 31.0 C and 12.5 C, respectively. Total precipitation for this period was 17.4 cm (Fig. 6).

Representative soil samples were taken on the date of ethylene application after the fertilization program for the season had been completed and the analyses are shown in Table 1.

The soil was alkaline with pH values ranging from 7.4 to 7.7. Electrical conductivity was low, indicating no salt problems. The range for soluble salts in the saturation extract was from 182 to 371 ppm. Nitrogen and phosphorus were indicated to be sufficient for crop growth.

Subsequent soil samples were taken from the test plots to determine whether ethylene would affect nitrate

Fig. 5. Daily maximum and minimum air temperatures at Willcox from May 15 to November 15, 1974.

Fig. 6. Precipitation at Willcox from May 15 to November 15, 1974.

Table 1. Chemical analyses of soil from experimental fields near Kansas Settlement.

Field	pH	Soluble salts in the saturation extract		ML EDTA	NO ₃ (ppm)	PO ₄ (ppm)
		(EC _e × 10 ³)	(ppm)			
I	7.6	0.53	371	0.25	49	24.0
II	7.4	0.26	182	0.25	39	7.9
III	7.7	0.38	266	0.20	31	8.2

nitrogen (Table 2). The values for nitrate levels in June and August are the means of 12 analyses. The July data are means of 10 analyses because of difficulties in sampling two plots under irrigation.

Table 2. Nitrate nitrogen in the upper 15 cm of soil from experimental fields near Kansas Settlement.

Sampling date (1974)	NO ₃ (ppm) in soil at four distances from ethylene injection			
	0.4 m	3.4 m	7.2 m	37.7 m
June 28	50 a ^{1/}	35 a	22 a	58 a
July 25	25 a	29 a	30 a	50 a
August 30	4 a	6 a	3 a	9 a

^{1/}Means within rows followed by the same letter are not significant at the 5% level according to the Student-Newman-Keuls test.

An analysis of variance showed no significant differences among samples taken on the same date. There was no consistent relationship between nitrate in soil and distance from ethylene application, probably due to high variability in the samples. Available soil nitrogen decreased with sampling data, except for an increase at 7.2 m in July.

Petiole samples were taken from the four rows in the test plots on three dates (Table 3). The July data are the means of 10 analyses and data for June and August are the means of 12 analyses.

Table 3. Sugarbeet petiole nitrate nitrogen of experiments near Kansas Settlement.

Sampling date (1974)	NO ₃ (ppm) in petioles at four distances from ethylene injection			
	0.4 m	3.4 m	7.2 m	37.7 m
June 28	3544 a ^{1/}	2321 a	2803 a	2452 a
July 25	5569 a	5657 a	6214 a	7901 a
August 30	2377 a	4012 a	2992 a	3707 a

^{1/} Means within rows followed by the same letter are not significant at the 5% level according to the Student-Newman-Keuls test.

Data in Table 3 show that nitrate levels in sugarbeet petioles increased from June 28 to July 25 and decreased on the August 30 sampling data. There were no significant differences among the means within sample dates and there appeared to be no consistent trend concerning nitrate nitrogen in petioles as a function of distance from the place of ethylene injection.

Correlations between soil and petiole nitrate values were calculated. The June data had a nonsignificant negative correlation of $-.2$; the July data had a positive correlation of $.46$, significant at the 1% level; and the August data had a positive correlation of $.36$, also significant at the 1% level. The means for the three dates had a positive correlation of $.43$, significant at the 1% level. Thus, there was a positive relationship overall between soil and petiole nitrate nitrogen.

Yield data for this experiment (Table 4) were analyzed using the least square method because one of the treated areas had yellowed leaves caused by a virus, while the check row was unaffected. Thus, the entire sample was omitted.

Table 4. Sugarbeet root weight, per cent sugar, and sugar yield of experiments in the Kansas Settlement area.

Yield parameter	Distance from ethylene injection			
	0.4 m	3.4 m	7.2 m	37.7 m
Beet weight (kg/plot)	120.8 a ^{1/}	114.0 a	113.8 a	110.3 a
Sugar (%)	11.6 a	11.8 a	11.8 a	10.7 a
Sugar (kg/ha)	6201 a	5824 a	5966 a	5178 a

^{1/} Means within rows followed by the same letter are not significantly different at the 5% level according to the Student-Newman-Keuls test.

An analysis of data indicated no significant differences in harvested beet weight, per cent sugar, or sugar/ha. The mean sugar yield (6201 kg/ha) obtained from the row nearest to ethylene injection was 20% higher than the sugar yield from the 50th row (5178 kg/ha). Mean beet weight and sugar yield declined with distance from the place of ethylene application. Although these findings were not conclusive evidence of a positive effect of ethylene on sugar yield, they encouraged further studies in 1975.

Experiment II

Environmental data for Experiment II were collected from a weather station located at Sacaton, Arizona, about 5 km from the test fields. The maximum air temperature on the day of ethylene application was 21 C (Fig. 7). The highest air temperature during the experimental period was 43 C on June 2. The lowest air temperature was -1 C on March 29. The average maximum and minimum air temperatures were 29.9 and 10.1 C, respectively. The trend in daily air temperatures was opposite that of the first experiment. At Sacaton, air temperatures tended to be cool during the early part of the experimental period, warming as summer approached. In the first experiment, air temperatures were warmer when the experiment was initiated in late May, cooling in the fall.

Fig. 7. Daily maximum and minimum air temperatures at Sacaton from March 15 to June 15, 1975.

During the second experimental period, the minimum air temperature dropped to 3 C on four dates, April 27 and 28, May 7, and May 22. Although sugarbeets are tolerant to low temperatures such as these, some suppression of the growth rate probably occurred.

Precipitation records from March 15 to March 31 for Sacaton are not available. Records for April 1 to June 15, 1975, are presented in Fig. 8. Total precipitation for this period was 2.5 cm.

Representative soil samples were taken from each field on March 24, 1975, after ethylene application was completed (Table 5). No further soil or petiole samples were collected during the course of this study.

The pH in these fields ranged from 7.7 to 8.1, representative of that found in the low desert valleys of this area and somewhat more alkaline than soil in the first experiment. The exchangeable sodium percentage was relatively low.

Nitrate and phosphorus levels were moderate in Fields II and III, but the nitrate level in Field I was high. At harvest, the sugarbeets in some parts of Field I exhibited rank top growth.

Mean yield data for this experiment are presented in Table 6. There were no significant differences among distances from ethylene injection in weight of beet, sugar percentage, or sugar/ha.

Fig. 8. Precipitation at Sacaton from April 1 to June 15, 1975.

Table 5. Chemical analyses of soil from experimental fields near Sacaton.

Field	pH	Soluble salts in the saturation extract		ESP	NO ₃ (ppm)	PO ₄ (ppm)
		(EC _C × 10 ³)	(ppm)			
I	7.7	3.80	2660	1.5	140.0	7.3
II	8.1	1.47	1029	3.5	17.3	6.3
III	8.1	2.71	1897	4.5	20.3	12.5

Table 6. Sugarbeet root weight, per cent sugar, and sugar yield of experiments in the Sacaton area.

Yield parameter	Distance from ethylene injection (m)			
	0.4	3.4	7.2	37.7
Beet weight (kg/plot)	116.6 a ^{1/}	113.8 a	108.7 a	118.2 a
Sugar (%)	16.0 a	15.9 a	15.5 a	15.6 a
Sugar (kg/ha)	5639 a	5453 a	5082 a	5559 a

^{1/} Means within rows followed by the same letter are not significantly different at the 5% level according to the Student-Newman-Keuls test.

Mean beet weight and sugar yield declined from the first through tenth rows, but due to high variability, this was not statistically significant. The mean sugar yield in the tenth row was 10% less than that of the first row. Mean sugar percentage varied by less than 1%.

Experiment III

The third experiment near Chandler differed from the previous ethylene field studies in that beets in only one field were treated. Therefore, mean yields reported for this experiment are based upon only four subsamples.

The daily maximum and minimum air temperatures for March 15 to July 31, 1975, were obtained from data reported by the weather station at Chandler, Arizona (Fig. 9). The highest air temperature recorded during the experimental period was 43 C on July 10 and 11. The minimum air temperature was 1 C on March 28. The average maximum air temperature was 32.1 C, while the average minimum air temperature was 13.0 C.

As was the case for the Sacaton area, several unseasonally cool periods occurred in May. On May 6, the air temperature dropped to 2 C, and on May 22, the minimum air temperature was 4 C. Total precipitation recorded during the experimental period was 2.0 cm, all occurring during March and April (Fig. 10).

Fig, 9, Daily maximum and minimum air temperatures at Chandler from March 15 to July 31, 1975.

Fig. 10. Precipitation at Chandler from March 15 to July 31, 1975.

The composite soil sample at the field test site was collected on the day of ethylene application (Table 7). The pH of this soil was alkaline, 7.8. Soluble salts and exchangeable sodium levels were low and therefore favorable for plant growth. Nitrogen and phosphorus levels were moderately low. No further soil or petiole samples were taken over the course of this experiment.

Table 7. Chemical analysis of soil from experimental field near Chandler

pH	Soluble salts in the saturation extract		ESP	NO ₃ (ppm)	PO ₄ (ppm)
	(EC _c × 10 ³)	(ppm)			
7.8	1.21	847	2.0	7.5	8.5

Yield data for Experiment III are presented in Table 8. Although there were no significant differences at the 5% level in these data, there was a 14% decline in mean beet weight and an 11% decline in mean sugar/ha from the first to the tenth row. At Sacaton, a similar nonsignificant depression occurred at the tenth row.

Table 8. Sugarbeet root weight, per cent sugar, and sugar yield of experiment near Chandler.

Yield parameter	Distance from ethylene injection (m)			
	0.4	3.4	7.2	37.7
Beet weight (kg/plot)	142.4 a ^{1/}	130.6 a	122.1 a	130.1 a
Sugar (%)	13.8 a	14.1 a	14.1 a	13.5 a
Sugar (kg/ha)	8435 a	7925 a	7490 a	7550 a

^{1/} Means within rows followed by the same letter are not significantly different at the 5% level according to the Student-Newman-Keuls test.

Combined Analysis Experiments I, II, and III

Mean beet root weight, sugar percentage, and sugar yield for the three field experiments are presented in Table 9. There were no significant differences among the means of these yield parameters. The coefficients of variability for root weight, sugar percentage, and sugar yield were 18, 12, and 21%, respectively. A combined statistical analysis was also performed excluding data from the control, row 50. Again, there were no significant differences. The CV values were reduced by less than 1%. This result indicates that variability in the control did not mask the significance of an ethylene effect on rows 1, 5, or 10.

Variability due to differences between years were factored out in all cases, however the differences were non-significant. Difference among fields was significant in all

Table 9. Mean sugarbeet root weight, per cent sugar, and sugar yield from three experiments in central and southeastern Arizona.

Yield parameter	Distance from ethylene injection (m)			
	0.4	3.4	7.2	37.7
Beet weight (kg/plot)	122.0 a ^{1/}	116.7 a	112.6 a	117.1 a
Sugar (%)	13.8 a	13.9 a	13.7 a	13.2 a
Sugar (kg/ha)	7233 a	6920 a	6617 a	6638 a

^{1/} Means within rows followed by the same letter are not significant at the 5% level according to the Student-Newman-Keuls test.

of the analyses. This might be expected because of differences in soil fertility, environment, and management. The interaction between treatment and field was not significant in any of the analyses.

Mean beet weight was highest in row one; 4, 8, and 4% higher than weights in rows 5, 10, and 50, respectively. The average sugar/ha was also highest in row one; 4, 9, and 9% higher than sugar/ha in rows 5, 10, and 50, respectively. There was less than a 1% range in mean sugar percentages.

Results obtained in this study appear to differ from those reported by A. H. Freytag and associates (27) in similar experiments. Although some increases in beet weight and sugar/ha were obtained, they were not enough to demonstrate a significant effect due to ethylene soil injection.

Freytag (26) reported 15% increases in tons of beets/ha and sugar/ha and up to 15% increases in cotton and sorghum (27). Ethylene was applied at the same rate and in the same manner as by Freytag et al.

The lack of statistically significant response to ethylene may have been due to soil heterogeneity within the test plots, a high degree of variability, soil salinity, or other factors. Lower rates of ethylene are effective in coarse textured soils in stimulating witchweed germination, while heavy rates are necessary in fine textured soils to have a similar effect (24). All soils used in this study were fine textured. Thus it is possible that the rate of application in the field experiments was not high enough to produce a response to ethylene in this study.

Experiment IV

Maximum air temperature during the experimental period was 41 C on two dates, June 12 and 14 (Fig. 11). The minimum air temperature was 7 C on three occasions, April 27 and May 5 and 6. The average maximum and minimum air temperatures were 33.5 and 14.4 C, respectively.

Minimum air temperature during germination and emergence was 7 C, occurring on the 6th day after planting. This temperature was not considered to be a limiting factor to germination. The average maximum and minimum air temperatures during this period were 30.6 and 11.0 C, respectively.

Fig. 11. Daily maximum and minimum air temperatures at Tucson from April 21 to June 15, 1975.

The daily average maximum and minimum relative humidities, April 22 to June 14, were 42 and 15.5%, respectively (Fig. 12). The lowest relative humidity was 8% on May 27 and June 3. A maximum value of 58% was recorded on May 18.

There was no measurable precipitation during the course of this experiment.

Since the soil temperature was recorded on an irregular schedule, no graph is presented. A comparison of values available for air and soil temperatures showed that, in general, there was a time lag of 2 to 4 hours in soil temperature. Also the soil temperatures averaged about 7 C cooler than the air temperatures at midday. On May 27 and 29, at the times of ethylene soil injection, the soil temperature was 20 C.

Soil used in this experiment was taken from the plow layer of Field I in the second experiment but no attempt was made to take a representative sample from the field. This soil had a moderately high pH of 8.0, typical of soils in the Sacaton area, and also had a favorable salt content (Table 10). The nitrate nitrogen content was high, similar to the level in Field I (63.0 vs. 140.0 ppm).

A summary of data for sugarbeet seedling emergence is presented in Table 11. Germination and emergence of plants were considered to be complete by 15 days. Total emergence and speed of emergence were highest in pots

Fig. 12. Daily maximum and minimum relative humidities at Tucson from April 21 to June 15, 1975.

Table 10. Chemical analysis of soil used in potted experiment at Tucson.

pH	Soluble salts in the saturation extract		ESP	NO ₃ (ppm)	PO ₄ (ppm)
	(EC _C × 10 ³)	(ppm)			
8.0	1.59	1113	3.5	63.0	14.3

Table 11. Effect of ethylene on sugarbeet seedling emergence.

Ethylene (l/pot)	Seedling emergence		
	Days to 50%	Speed ^{1/}	Total (%)
0	8.4 a ^{2/}	0.113 a	55 a
0.5	8.5 a	0.132 a	65 a
1.0	8.9 a	0.103 a	50 a
2.0	8.5 a	0.114 a	57 a

^{1/}As calculated by the McGuire method.

^{2/}Numbers in columns followed by the same letter are not significantly different at the 5% level according to the Student-Newman-Keuls test.

receiving 0.5 l of ethylene, but differences among treatment means were not significant.

There were no emerged seedlings in pots receiving the Ethrel treatments. Ethrel is an acidic compound. After Ethrel was applied, a bubbling action occurred, and when the soil surface dried, vescicles and a thin crust were observed. The bubbling probably resulted from an acid-base reaction and subsequent CO_2 liberation. The possibility exists that ethylene was involved in this reaction.

The ethylene gas and Ethrel treatments were applied 25 hours after the initiation of seed imbibition. This timing was used because ethylene has been reported to be stimulatory to germination of certain species before radicle emergence, but inhibitory after radicle emergence. In this experiment, germination rate was not measured, and ethylene did not exert a great enough affect on emergence to be significant.

On May 27, 1975, a second treatment of ethylene was applied to pots that had received the preemergence soil injection. On May 29, three higher rates of ethylene, 3.0, 4.0, and 5.0 l/pot, were applied to pots that were previously untreated (Table 12).

The mean fresh weight of whole plants and of excised tops of sugarbeet seedlings receiving 3.0 l/pot ethylene ranked first among the seven treatments. However, there were no significant differences among these means or the

Table 12. Effect of ethylene injected into the soil on seedling weight of sugarbeets grown in pots.

Ethylene (l/pot)	Fresh weight of whole plant (g)	Fresh weight of top (g)	Dry weight of top (g)
0	42.2 a ^{1/}	31.8 a	3.90 a
0.5	45.6 a	32.5 a	3.91 a
1.0	42.9 a	31.7 a	4.01 a
2.0	42.1 a	32.6 a	3.88 a
3.0	48.4 a	34.5 a	4.00 a
4.0	46.5 a	34.3 a	3.95 a
5.0	44.0 a	32.1 a	3.77 a

^{1/} Numbers in columns followed by the same letter are not significantly different at the 5% level according to the Student-Newman-Keuls test.

means for dry weight of tops. The range in dry weights was only 0.24 g.

Difficulty was encountered in obtaining meaningful root weights due to variability in the amount of root material lost during collection. Clay platelets adhered tightly to the roots.

Soil-injected ethylene did not have a statistically significant effect on the weight of sugarbeet seedlings grown in pots. This was the same conclusion drawn in the discussion of the field experiments, though data suggested a yield increase. Rates of ethylene application per unit

area were higher in the potted experiment than in the field experiments, however the volume of soil in pots alters this relationship. Ethylene diffuses more readily from pots, changing the time of exposure. The conclusion must be drawn that the presence of exogenous ethylene in soil over a short term does not significantly affect the yield of sugargeets.

SUMMARY AND CONCLUSION

Ethylene was soil injected in three sugarbeet field experiments and in a potted experiment. The object of these tests was to determine the effect of ethylene injection into the soil atmosphere on sugarbeet yield parameters.

The first field experiment was located in southeastern Arizona in 1974. Ethylene gas was injected into a furrow 20 cm below the soil surface, at a rate of 6.2 kg/ha. Each test plot consisted of a row located 1, 5, 10, or 50 rows from the place of ethylene injection. The rows were 76 cm apart.

Beets in the first experiment were mechanically harvested, weighed, and sampled to determine the sugar content. The production of sugar/ha was 20% higher in the row nearest the applied ethylene than in the row located 37.7 m from the place of application. Although not significantly different, this finding prompted further field experiments and a potted study in 1975.

In March of 1975, field experiments at Sacaton and Chandler were initiated. The methodology used for these experiments closely followed that of the first field experiment. There were no significant differences at the 5% level among the ethylene treatment on beet weight, sugar

percentage, or sugar/ha in any of these field tests because of high variability.

A potted experiment, in a randomized complete block design, was conducted at Tucson from April to June, 1975. The objective was to determine the effect of ethylene and Ethrel on seedling emergence and weight of sugarbeet seedlings.

Ethylene was injected into pots 25 hours after the initiation of seed imbibition at a rate of 0.5, 1.0, or 2.0 l/pot. Ethrel was applied to the soil surface in a tap water solution at a rate of 0, 20, 40, or 80 ml/l. There were no emerged seedlings in pots receiving applications of Ethrel. There were no significant differences in total emergence, speed of emergence, or days to 50% emergence among seedlings in pots receiving the ethylene treatments.

A second soil injection of ethylene was performed in the 6th week after planting. Pots receiving the pre-emergence treatment of ethylene were again treated using similar rates, and pots having no previous treatment received an ethylene injection at the rate of 3.0, 4.0, or 5.0 l/pot. There were no significant differences among treatments in fresh or dry seedling weight.

The results in this study were variable and thus do not support the conclusion that soil injections of ethylene can be used to increase yield of sugarbeets under the described conditions. Further research should be directed

toward finding the optimum rate and date of application, and the optimum soil and environmental conditions.

REFERENCES

1. Abeles, F. B. 1972. Biosynthesis and mechanism of action of ethylene. *Ann. Rev. Plant Physiol.* 23: 259-292.
2. Abeles, F. B. 1973. Ethylene in plant biology. Academic Press, N. Y.
3. Abeles, F. B., and J. Lonski. 1969. Stimulation of lettuce seed germination by ethylene. *Plant Physiol.* 44:277-280.
4. Abrams, G. J. von, and H. K. Pratt. 1967. Effect of ethylene on the permeability of excised cantalope fruit tissue. *Plant Physiol.* 42:299-301.
5. Andreae, W. A., M. A. Venis, F. Jursie, and T. Dumas. 1968. Does ethylene mediate root growth inhibition by indole-3-acetic acid? *Plant Physiol.* 43:1375-1379.
6. Balls, A. K., and W. S. Hales. 1940. The effect of ethylene on freshly harvested wheat. *Cereal Chem.* 17:490-494.
7. Baur, A. H., and S. F. Yang. 1969. Precursors of ethylene. *Plant Physiol.* 44:1347-1349.
8. Biale, J. B., R. E. Young, and A. J. Olmstead. 1954. Fruit respiration and ethylene production. *Plant Physiol.* 29:168-174.
9. Burg, S. P. 1962. The physiology of ethylene formation. *Ann. Rev. Plant Physiol.* 13:265-302.
10. Burg, S. P. 1968. Ethylene, plant senescence and abscission. *Plant Physiol.* 43:1503-1511.
11. Burg, S. P., and E. A. Burg. 1965. Ethylene action and the ripening of fruits. *Science* 148:1190-1196.
12. Burg, S. P., and E. A. Burg. 1966. The interaction between auxin and ethylene and its role in plant growth. *Proc. Nat'l. Acad. Sci.* 55:262-266.

13. Burg, S. P., E. A. Burg, and R. Marks. 1964. Relationship of solute leakage to solution toxicity in fruits and other plant tissues. *Plant Physiol.* 39:185-195.
14. Burg, S. P., and K. V. Thimann. 1959. The physiology of ethylene formation in apples. *Proc. Nat'l. Acad. Sci.* 45:335-344.
15. Chadwick, A. V., and S. P. Burg. 1967. An explanation of the inhibition of root growth caused by indole-3-acetic acid. *Plant Physiol.* 42:415-420.
16. Chadwick, A. V., and S. P. Burg. 1970. Regulation of root growth by auxin-ethylene interaction. *Plant Physiol.* 45:192-200.
17. Chalutz, E., and J. E. DeVay. 1969. Production of ethylene in vitro and in vivo by *Ceratocystis fimbriata* in relation to disease development. *Phytopathology* 59:750-755.
18. Cooke, A. R., and D. I. Randall. 1968. 2-Haloethane-phosphoric acids as ethylene releasing agents for the induction of flowering in pineapple. *Nature* 218:974-975.
19. Crocker, W., A. E. Hitchcock, and P. W. Zimmerman. 1935. Similarities in the effects of ethylene and the plant auxins. *Cont. Boyce Thompson Inst.* 7: 231-248.
20. Davis, J. B., and R. M. Squires. 1954. Detection of microbially produced gaseous hydrocarbons other than methane. *Science* 119:381-382.
21. Denny, F. E. 1935. Testing plant tissue for emanations causing leaf epinasty. *Cont. Boyce Thompson Inst.* 7:341-347.
22. Doubt, S. L. 1917. The response of plants to illuminating gas. *Bot. Gaz.* 63:209-224.
23. Egley, G. H., and J. E. Dale. 1970. Ethylene, 2-chloroethylphosphonic acid and witchweed germination. *Weed Sci.* 18:586-589.
24. Eplee, R. E. 1975. Ethylene: A witchweed seed germination stimulant. *Weed Sci.* 23:433-436.

25. Esashi, Y., and A. C. Leopold. 1969. Dormancy regulation in subterranean clover by ethylene. *Plant Physiol.* 44:1470-1472.
26. Freytag, A. H. 1974. The effect of soil-applied ethylene on sugarbeet yield and storage. Paper presented at Annual Plant Physiology Meeting, Cornell University.
27. Freytag, A. H., C. W. Wendt, and E. P. Lira. 1972. Effects of soil-injected ethylene on yields of cotton and sorghum. *Agron. J.* 64:524-526.
28. Gane, R. 1934. Production of ethylene by some ripening fruits. *Nature* 134:1008.
29. Goeschl, J. D., L. Rappaport, and H. K. Pratt. 1966. Ethylene as a factor regulating the growth of pea epicotyls subjected to physical stress. *Plant Physiol.* 41:877-884.
30. Handbook of Chemistry and Physics. 1964. 45th edition. Chemical Rubber Company, Cleveland.
31. Jones, R. L. 1968. Ethylene enhanced release of α -amylase from barley endosperm. *Plant Physiol.* 43:442-444.
32. Ketring, D. L., and P. W. Morgan. 1969. Ethylene as a component of the emanations from germinating peanut seeds and its effect on dormant Virginia-type seeds. *Plant Physiol.* 44:326-330.
33. Knight, L. I., and A. T. Crocker. 1913. The toxicity of smoke. *Bot. Gaz.* 55:337-371.
34. Lewis, L. N., and J. C. Bakhshi. 1968. Interaction of indoleacetic acid and gibberellic acid in leaf abscission control. *Plant Physiol.* 43:351-359.
35. Lieberman, M., A. T. Kunishi, L. W. Mapson, and D. A. Wardale. 1965. Ethylene production from methionine. *Biochem. J.* 97:449-459.
36. Lira, E. P., and A. H. Freytag. 1971. Effect of ethylene and 2-3-5 triiodobenzoic acid on soybean seedlings grown in hydroponic culture. *Trans. Ill. Acad. Sci.* 64:309-312.

37. Lyons, J. M., and H. K. Pratt. 1964. An effect of ethylene on swelling of isolated mitochondria. Arch. Biochem. Biophys. 104:318-324.
38. McAuliffe, C. 1966. Solubility in water of paraffin, cycloparaffin, defin, acetylene, cycloolefin, and aromatic hydrocarbons. J. Phys. Chem. 70:1267-1275.
39. McGuire, J. D. 1962. Speed of germination--aid in selection and evaluation for seedling emergence and vigor. Crop Sci. 2:176-177.
40. Mehard, C. W., and J. M. Lyons. 1970. A lack of specificity for ethylene induced mitochondrial changes. Plant Physiol. 46:36-39.
41. Meheriuk, M., and M. Spencer. 1964. Ethylene production during germination of oat seeds and *Penicillium digitatum* spores. Can. J. Bot. 42:337-340.
42. Morgan, P. W. 1969. Stimulation of ethylene evolution and abscission in cotton by 2-chloroethane phosphonic acid. Plant Physiol. 44:337-341.
43. Morrison, R. I., and R. N. Boyd. 1973. Organic Chemistry. 3rd edition. Allyn and Bacon Inc., Boston.
44. Nelson, J. M. 1975. Research Agronomist, Mesa Experimental Station, personal communication.
45. Nickerson, W. J. 1948. Ethylene as a metabolic product of the pathogenic fungus, *Blastomyces dermatitidis*. Arch. Biochem. 17:225-233.
46. Nord, F. F., and F. W. Frank. 1928. On the mechanism of enzyme action. J. Biol. Chem. 79:27-51.
47. Pratt, H. K., and J. D. Goeschl. 1969. Physiological roles of ethylene in plants. Ann. Rev. Plant Physiol. 20:541-584.
48. Radin, J. W., and R. W. Loomis. 1969. Ethylene and carbon dioxide in the growth and development of cultured radish roots. Plant Physiol. 44:1584-1589.
49. Roberts, D. W. A. 1951. Some effects of ethylene on germinating wheat. Can. J. Bot. 29:10-25.

50. Robinson, R. W., S. Shannon, and M. D. DeLaGuardia. 1968. Regulation of sex expression in cucumber. *Biol Sci.* 19:141-142.
51. Rudich, J., A. H. Halevy, and N. Kedar. 1969. Increase in femaleness of three cucurbits by treatment with Ethrel, an ethylene releasing compound. *Planta* 86:69-76.
52. Sacher, J. A. 1967. Studies of permeability, RNA, and protein turnover during ageing of fruit and leaf tissues. *Soc. Exptl. Biol. Symp.* 21:269-304.
53. Shaw, F. H. 1935. The mechanism of the action of ethylene on cell processes. *Austr. J. Exp. Biol. Med. Sci.* 13:95-102.
54. Smith, A. M. 1973. Ethylene as a cause of soil fungistasis. *Nature* 246:311-313.
55. Smith, K. A., and S. W. F. Restall. 1971. The occurrence of ethylene in anaerobic soil. *J. Soil Sci.* 22:430-443.
56. Smith, K. A., and R. S. Russell. 1969. Occurrence of ethylene, and its significance, in anaerobic soil. *Nature* 222:769-771.
57. Spencer, M., and A. O. Olsen. 1965. Ethylene production and lipid mobilization during germination of castor beans. *Nature* 205:699-700.
58. Stewart, R. N., M. Lieberman, and A. T. Kunishi. 1974. Effects of ethylene and gibberellic acid on cellular growth and development in apical and subapical regions of etiolated pea seedling. *Plant Physiol.* 54:1-5.
59. Takayanagi, K., and J. F. Harrington. 1971. Enhancement of germination rate of aged seeds by ethylene. *Plant Physiol.* 47:521-524.
60. Toole, V. K., W. K. Bailey, and E. H. Toole. 1964. Factors influencing dormancy of peanut seeds. *Plant Physiol.* 39:822-832.
61. Traub, H. P., W. C. Cooper, and P. C. Reece. 1939. Inducing flowering in the pineapple, *Ananas sativus*. *Proc. Amer. Soc. Hort. Sci.* 37:521-525.

62. Ulrich, A. 1946. Plant analysis as a guide in the fertilization of sugar beets. J. Amer. Soc. Sugar Beet Technol. 1946:88-95.
63. U. S. Department of Commerce, 1974-1975. Climatological data for Arizona. Vol. 78, no. 5-Vol. 79, no. 6.
64. Vacha, G. A., and R. B. Harvey. 1927. The use of ethylene, propylene, and similar compounds in breaking the rest periods of tubers, bulbs, cuttings, and seeds. Plant Physiol. 2:187-192.
65. Warner, H. L., and A. C. Leopold. 1967. Plant growth regulation by stimulation of ethylene production. Bioscience 17:722.
66. Yang, S. F. 1969. Ethylene evolution from 2-chloroethylphosphoric acid. Plant Physiol. 44:1203-1204.
67. Zimmerman, P. W., and A. E. Hitchcock. 1933. Initiation and stimulation of adventitious roots caused by unsaturated hydrocarbon gasses. Cont. Boyce Thompson Inst. 5:351-359.