# EFFECT OF ENVIRONMENTAL FACTORS (2-CHLOROETHYL) PHOSPHONIC ACID AND SILVER THIOSULFATE ON BUD ABORTION IN *TAGETES ERECTA* L. CV. MOONSHOT

By

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ABSTRACT

EFFECT OF ENVIRONMENTAL FACTORS
(2-CHLOROETHYL) PHOSPHONIC ACID AND SILVER THIOSULFATE
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Temperatures above 23°C alone or interacting with low quantum flux (QFD<400 $\mu Em^{-2}s^{-1}$) and water stress was the main environmental factor favoring apical and lateral bud abortion in Tagetes erecta L. cv. Moonshot. These environmental factors appear to influence endogenous ethylene production that accelerates maturity of the apical bud which ceases its development and finally aborts. The abortion of the apical bud results in an outgrowth of laterals which subsequently show the same abortion symptoms.

Silver Thiosulfate (STS) applied to the foliage at 50mg of Silver Nitrate ($AgNO_3$) in 292mg of Sodium Thiosulfate 30 to 45 days after sowing (during terminal bud development) prevented apical and lateral bud abortion in the presence of (2-chloroethyl) phophonic acid or environmental conditions favoring ethylene synthesis and action.

DEDICATION

To Rena, George and Tonia

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# INTRODUCTION

During the last two decades the bedding plant industry grew rapidly nationwide increasing from 32.8 million dollars in wholesale value in 1959 (Carlson and Rowley, 1980) to about 208 million dollars in 1981 (U.S.D.A., 1982). Marigolds are one of the five leading flowering annuals grown nationwide. There are two different species of marigolds, Tagetes patula L. and Tagetes erecta L. The introduction of many dwarf African varieties has increased the demand for Tagetes erecta L.

The new "Space Series" dwarf African types have a physiological problem that manifests itself in the abortion of the terminal bud on a significant percentage of the plants; up to twenty percent of the apical flower buds fail to reach anthesis. It is estimated that 200,000 dollars are lost annually because of this disorder. Preliminary experiments indicated that three environmental factors, temperature, light and water stress influence apical bud abortion. These environmental factors also cause terminal bud abortion in other plant genera such as Lilium longiflorum Thumb., Chrysanthemum morifolium Ram., Narcissus sp.L., Tulipa sp.L., Iris x Hollandica cv. Wedgwood and Rosa hybrida cv. Baccara. Leaf epinasty and adventitious root formation observed in plants with aborted buds indicated possible ethylene involvement.

Stressed plants were found to produce ethylene. Therefore the objectives of this work were (a) to investigate the role of temperature, light, moisture stress and ethylene on bud abortion in Tagetes erecta L. cv. Moonshot and (b) to determine the morphological, anatomical and physiological characteristics of this abnormality.

# LITERATURE REVIEW

1. Plant Systematics and Genetics. Tagetes L. species are among the most important genera of commercial bedding plants. Tagetes L. species are included in Compositae family, subfamily Tubuliflorae, tribe Heliantheae (Gleason and Cronquist, 1963). Tagetes erecta L., also known as the African marigold, is native to Mexico and Central America and is relatively compact (30-40cm), with large flower heads (7-9cm diam.) and conspicuous rays. T.erecta L. has been bred extensively in order to obtain new varieties. The diploid hybrid "Moonshot" is one of the most important F hybrids among the "Space Age" series.

2. Cultural and Environmental Factors Related to Meristematic Abnormalities in Marigolds and Other Ornamentals.

Temperature. Night temperatures of 13-16°C after transplanting with 3-5°C warmer during the day, result in a high quality crop. Carlson and Rowley (1980) reported that lower day (10°C) and night (8°C) temperatures two to three weeks before flowering resulted in better flower quality. Temperatures above 30°C during flower initiation and the first stages of bud development inhibited normal development and resulted in apical growth retardation and death of the apical meristem (Armitage, 1980).

Futura and Nelson (1953) found that the critical temperature for heat delay in chrysanthemum is approximately 30°C and cultivars

sensitive to high temperatures may form "crown buds" which fail to reach anthesis if temperatures remain above 30°C. Fluctuating day and night temperatures are associated with "calyx splitting" in carnations (Szendel, 1938 and Holiday and Watson, 1953) but Wagner and Holley (1953) suggested that other factors may be involved. Nicols (1971) reported that as carnation flower buds developed and reproductive organs matured, they became more sensitive to ethylene. Buds were also more sensitive as the temperature increased from 2 to 21°C. This response of carnation buds and open flowers to ethylene is known as "sleepiness" and is determined by the length of the exposure and the ethylene concentration (Crocker and Knight, 1908 and Nicols, 1971).

Light. African marigolds respond to daylength in a quantitative manner. T.erecta cv. Moonshot under long night (15hrs) conditions flowers rapidly but internodes are not elongated and basal branching is somewhat reduced. In contrast, long days delay flowering but promote basal branching and long internodes. Marigolds are most sensitive to photoperiod about thirty days after germination (Carpenter, 1976).

Mastalerz (1965) found that flower buds of Easter lily (Lilium longiflorum Thumb.) and bulbous iris (Iris x Hollandica cv. Wedgwood) may stop developing and die during forcing. Bud abortion was more severe when light intensities were low and temperatures relatively high. At temperatures above 27°C 18 to 83 percent of the buds aborted. This abnormality did not occur on plants held at 16°C or 27°C under high light intensities. He suggested that the controlling factor was the supply of photosynthates available to the developing flower bud.

Sensitivity of early flowering stages to light intensity was found also in tomato (Kinet, 1977), iris (Mae and Vonk, 1974) and bougainvillea (Hackett and Sachs, 1966). Mor and Halevy (1980) showed that low intensity lighting of young growing rose shoots promoted flower bud development and prevented atrophy under low light conditions. Bud development was promoted due to increased carbohydrate translocation to the shoot tip.

3. Growth and Developmental Effects of Ethylene. Ethylene triggers biochemical reactions that can ultimately cause developmental changes such as fruit ripening, abscission of leaves and flower buds, senescence, growth (elongation of stems and roots, swelling, leaf expansion), flowering and sex expression (Abeles, 1973).

a. Physiological Effects. Ridge and Osborne (1970) and Beutelman and Kende (1977) reported that increased ethylene production is related to atrophy and breakdown of plant tissue. Apelbaum and Burg (1972) reported that ethylene depresses DNA synthesis and cell division in meristematic tissues. Other reports indicate that cell division and DNA synthesis are inhibited in the root tip, stem apex and lateral buds (Apelbaum et al., 1972, Kang and Burg, 1973). Apelbaum and Burg (1971) found that the polarity of cell expansion is also altered due to changes in the direction of cellulose microfibril deposition at the inner surface of the cell wall in pea. Elmer (1932), Burg and Burg (1968), and Maxie and Crane (1968) reported that when ethylene was applied, cell division and growth of the apex was inhibited almost

completely in buds of pea, petunia,potato and fig fruits. Holm and Abeles (1967) observed that DNA content and growth were reduced in the apical region of soybean seedlings exposed to ethylene and these changes are correlated with the mitotic index. DNA synthesis inhibition began about two hours after ethylene was applied to etiolated pea seedlings cv. Alaska and intensified progressively (Kang and Burg, 1973). Apelbaum and Burg (1972) suggested that ethylene interferes with cell division by blocking a mitotic stage before prophase in apical and lateral buds. In their experiments the number of metaphase figures was reduced by 27 percent after two hours treatment with 50 1/1 ethylene, by 50 percent after six hours and within ten hours inhibition was almost complete.

Morgan and Gausman (1966) working with intact cotton and cowpea plants suggested that ethylene through its effect on auxin transport and synthesis may cause localized shortages and surpluses of auxin which contribute to the symptoms associated with the ethylene response. Numbers of researchers (Valdovinos et al. 1967, Ernest and Valdovinos, 1971, and Abeles, 1966) reported observations indicating that ethylene decreased levels of diffusible auxin in plant tissues through its influence on auxin synthesis.

Ethylene inhibition of cell expansion and division is rapid but the responses were observed after exposure to exogenous ethylene. Experiments have to be conducted to determine the exact role of ethylene at levels comparable to those occurring naturally within the plant.

b. Morphological Effects.

Apical Bud Inhibition. Zimmerman et al. (1930) first reported the effect of ethylene on meristematic growth. Small quantities of illuminating gas produced such responses as epinastic growth, abscission of leaves, buds, flowers and fruits; buds "killed but still clinging to plant"; buds stimulated to open prematurely and changes in color in fuschia, tomato, Ageratum, potato and other plants. Two years later Hitchcock et al. (1932) observed that young flower buds of lily, narcissus and tulip were killed by illuminating gas containing four percent ethylene at concentrations of 1 to 10,000ppm or higher. In some cases lower concentrations killed the flower buds, particularly in lily.

Chemical compounds capable of releasing ethylene such as (2-chloroethyl)phosphonic acid (ethephon, ethrel), provide a means of inducing ethylene responses under field conditions. Andersen working on peas in 1970 and 1976 found that ethephon could break apical dominance. He suggested that this effect was due to the release of ethylene within the plants and subsequent ethylene interference either with auxin transport (Morgan and Gausman, 1966) or nutrient supply to the inhibited buds. Andersen believed that the effect of ethephon on apical dominance was dependent on the nutritional status of the plant. If enough carbohydrate was present due to high rates of photosynthesis, ethephon treatment diverted growth activity from the apex to the lateral buds.

Burg and Burg (1968) studying the effect of ethylene on bud development in pea seedlings found that low concentrations of applied ethylene were highly effective in retarding bud development. Ethylene concentrations of 0.2 and 2.0 ppm half inhibited and completely suppressed the growth of buds on nodal sections. Low concentrations of ethylene (1 ppm) were also found to prevent the opening of immature carnation buds (Mastalerz, 1977). Zieslin and Halevy (1976c) reported that applications of ethylene producing compounds markedly increased flower bud atrophy in Baccara roses.

Lateral Bud Growth. Yeang and Hillman (1981) suggested that the promotion of axillary bud development by ethylene action on the apical shoot was associated with the availability of diffusible ethylene in the tissues of the treated shoot. Ethephon stimulated axillary bud growth when applied to the apical shoot in bean, but was ineffective when applied directly to the axillary bud. It seems that a simple stimulatory effect of ethylene on bud development does not occur. It has been shown that ethylene inhibits cell division in apical meristems (Apelbaum et al., 1972) evidently by inhibition of DNA synthesis (Kang and Burg, 1973). The reduced activity of the apical meristem may also lead to diminished auxin synthesis (Ernest and Valdovinos, 1971) compounded by ethylene inhibition of auxin transport (Morgan and Gausman, 1966). The effect on lateral buds should be similar. According to Weaver et al. (1972), ethylene accumulates in the apical regions no matter where it is applied, moving with photosynthate, thus if no or little photosynthate transport takes place, ethylene is

presumably not transported either. Retardation of apical shoot growth was always observed when ethylene or ethepon was applied or when the apical shoot was physically constricted (Yeang and Hillman, 1981), therefore inhibition of apical growth could be the main cause of lateral bud growth. When the apical bud is inhibited nutrients and other growth factors are directed to the lateral buds, so that lateral bud growth subsequently occurs.

Induction of Roots and Root-Hairs. Root initiation from leaves, stems, flower stems and preexisting roots in a variety of plants can be induced by ethylene. The phenomenon has been observed by a number of investigators but the most thorough survey was completed by Boyce Thomson Institute investigators in the early 1930's (Zimmerman and Hitchcock, 1933, Zimmerman et al. 1930 and 1933, Zimmerman and Wilcoxon, 1935). Working with 202 different varieties of plants they found that roots were initiated by ethylene and its analogs CO (Zimmerman et al, 1933), acetylene and propylene (Zimmerman and Hitchcock, 1933). Roots are formed on the region of stem elongation in tobacco and hydrangea; over the whole stem in coleus, tomato and marigold or at nodes in cosmos. Rooting from leaves of tomato and heliotrope was also induced by ethylene. When varieties of Tagetes erecta L. were treated with various concentrations of ethylene or its analogs, roots appeared first near the base, then further up the stem. Additional ethylene treatments induced secondary roots from adventitious roots. During the last two decades a number of

investigators (Chadwick and Burg, 1967 and Abeles, 1973) have observed the formation of root hairs due to ethylene treatments on plants such as Pisum sativum, Vicia Faba L., Sinapis alba, Cheiranthus cheiri and Raphanus sativa.

Apelbaum and Burg (1972) suggested that the phenomenon of adventitious root formation may be due to ethylene irreversibly inhibiting polar auxin transport. Ethephon or ethrel increased rooting in fifteen herbaceous species and some woody plants such as apple and blueberry (Cummins and Fiorino, 1969, Kender et al., 1969).

Leaf Epinasty. One of the most rapid and visible responses of tomato, sunflower and marigold (T.erecta L. and T.patula L.) to ethylene is the downward growth of the petioles known as epinasty. Early in 1917 Doupt reported a "definite striking and not easily mistaken" response of tomato, Salvia and Hibiscus plants to illuminating gas. Leaf abscission, epinasty of petioles and tissue proliferation were observed. The epinastic response was primarily a sharp bending downward of the leaflets at the base and a ventral inrolling of the edges of the leaflets. This was a result of a rapid expansion of the cells in the upper side of the petiole rather than those in the lower side, due to the inhibition of lateral auxin transport to the lower side of the petiole (Lyon, 1970). Epinasty was observed in 89 of 202 different species and cultivars tested by Crocker et al. in 1932. T.erecta L. and T.patula L. showed marked epinasty of the leaves. Young leaves curved along the whole length of the petioles, while

older leaf petioles bent near the stem. Older leaves showed only a slight degree of recovery. Gilbert and Sink (1970) observed similar responses in a number of plants. Saltveit et al. (1979) found that mechanically bent petioles of poinsettia plants produced three to seventy times more ethylene than petioles from unstressed plants. Exposure of potted poinsettia plants to 10 ppm ethylene in air produced the same pattern of epinasty in four hours as was produced by 24 hours of mechanical stress.

Abeles (1973) reported that the minimum amount of ethylene required to cause epinasty varied between 0.01 ppm for African marigolds to 0.1 ppm for tomatoes. The response is specific for ethylene or its analogs, is sensitive to low concentrations, occurs rapidly and requires little in the way of experimental setup to observe; therefore epinasty is a useful bioassay for ethylene detection.

Direct involvement of ethylene in inducing epinasty has been suggested by Beyer (1976) and Sacalis J.N. (1978) since silver nitrate ($AgNO_3$) reduced the response, perhaps due to the antagonistic role of $Ag^+$ to ethylene action (Beyer, 1976 and Saltveit et al., 1978).

Imperfect Flowers. The formation of imperfect flowers was observed in a number of floriculture crops. According to Mastalerz (1977) formation of imperfect flowers is genetically controlled, but variations in air temperature, light, water and air pollutants, i.e. ethylene and its analogs could be associated with the development of imperfect flowers on mums, (Miller and Kiplinger, 1962 and Cox, 1969) roses and carnations.

4. Ethylene Antagonists.

Ethylene Synthesis Inhibitors. Ethylene production can be suppressed by inhibitors which block certain reactions during ethylene biosynthesis such as aminoethoxyvinylglycine (AVG) and aminooxyacetic acid (AOA). These chemicals suppress the synthesis of the natural precursor of ethylene, 1-aminocyclopropane-1-carboxylic acid (ACC). Ethylene production may also be inhibited by factors which interfere directly with conversion of ACC to ethylene such as 2,4-dinitrophenol (DNP), $CO_2$ and high temperatures (Yang, 1980).

Ethylene Action Inhibitors. Beyer (1976) showed that $Ag^+$ inhibits ethylene action. This has been confirmed by a number of researchers (Beutelmann and Kende, 1977, Halevy and Kofranek, 1977, and Saltveit et al., 1978. Silver ion ($Ag^+$) applied as its nitrate salt ($AgNO_3$) effectively prevents the classical "triple" response in intact etiolated pea plants, senescense in orchid plants (Beyer, 1976a) and epinasty in tomato plants (Beyer, 1976b). The inability of applied ethylene to elicit normal ripening in silver treated tissue of apple, tomato and banana fruits suggests that $Ag^+$ interferes with an early and initial critical step in ethylene action in the ripening sequence (Saltveit et al., 1978).

The usefulness of $AgNO_3$ is somewhat limited by its immobility within plant tissue and by its phytotoxicity at high concentrations. Despite this and the fact that the mode of $Ag^+$ action is unknown, Beyer (1976a) and Yeang and Hillman (1981) suggested that $AgNO_3$ may be a useful tool to investigate various aspects of growth such as

meristematic inhibition, adventitious root formation and leaf epinasty.

Veen and Van de Geijn (1978) discovered that silver nitrate complexed with thiosulfate was extremely mobile within the plant and very efficient in extending vase life of cut carnations since complexed silver remains active within the tissue for an extended period. Use of silver thiosulfate (STS) applied as spray to foliage or buds significantly reduced petal, bud and flower abscission in Geranium, Zygocactus, Calceolaria and Bougainvillea by blocking ethylene action for a period of twenty-one to twenty-eight days (Miranda, 1980, Reid et al., 1980, Cammeron and Reid, 1983 in press). Silver thiosulfate treatments also markedly extended shelf and vase life of carnation, Gypsophila and Gladiolus flowers when applied up to three days before cutting. Silver thiosulfate can also prevent premature wilting of plants induced by ethylene (Farhoomand et al., 1980, Halevy and Mayak, 1981, Mor et al., 1980, Nicols et al., 1982).

5. Environmental Factors Influencing Ethylene Production.

Temperature. Temperature greatly influences ethylene production, the optimum being about 30°C. As temperature rises above 30°C the rate of production falls gradually until ethylene evolution ceases at 40°C (Burg 1962, Abeles, 1973). Field (1981) reported that a rise in temperature from 25 to 35-37.5°C approximately doubled the rate of ethylene production in bean (Phaseolus vulgaris L.) leaves. Ethylene production declined rapidly above 37.5°C which suggested a loss of integrity in the ethylene synthesizing system. Similar results were observed by Saltveit and Dilley (1978) in experiments on excised

segments of etiolated pea plants (Pisum sativum).

Light. Ethylene production can be regulated by light. Depending on the tissue involved, light can increase or decrease the rate of ethylene production which may mediate effects formerly attributed solely to light. Andersen (1976) found that inhibition of pea apical buds and maximal growth of laterals was obtained with high irradiance. Subsequent ethephon treatments of young plants resulted in lateral growth but the growth was significant only when apical dominance was already weakened by high irradiance and/or CO. Changes in ethylene production in the two upper shoots of rose plants were measured as affected by decreasing temperature and high light intensities, factors which encourage flower atrophy (Zieslin and Halevy, 1976). Ethylene production was much higher under conditions of full light than under fifty percent shade.

Annon (1977) reported that blue plus far-red (B/FR) caused a rapid rise in ethylene evolution from peach apices. A higher endogenous ethylene content was also found under B/FR relative to blue and shade conditions.

Water. Andersen (1976) found that waterlogged plants have reduced apical dominance and plants under drought conditions exhibit strong apical dominance. Kawase (1972) proposed the involvement of ethylene in apical dominance since waterlogging often gives rise to endogenous ethylene production. Studies on a variety of horticultural plants such as tomato (Lycopersicon esculentum Mill.), marigolds (T.patula, T.erecta) and broad beans (Vicia Faba L.) revealed that the level of

ethylene in waterlogged plants exceeded those in control plants (El-Beltagy and Hall, 1974, Jackson and Cambell, 1975, Kawase, 1972) as the result of at least two processes (a) anaerobic stimulation of ethylene production and (b) the "water jacket effect" preventing ethylene diffusion out of the roots (Bradford and Yang, 1981).

## MATERIALS AND METHODS

Five experiments were conducted on apical bud abortion in T.erecta L. cv. Moonshot. The first two investigated the effect of temperature, light and moisture. Their results led to the design of three other experiments investigating the effect of ethylene and ethylene antagonists on bud abortion. For each experiment, seeds of T.erecta L. cv. Moonshot were germinated at 26-28°C under mist in plastic flats. Seven days before transplanting, the flats were moved from the mist bench into a greenhouse environment (20°C Day and 14°C Night ±2°C). Transplanted plants were grown in a peat-lite medium in 8.75cm plastic cells and fertilized with 20 N -8.7 P -7.7 K, providing 200 ppm N at each irrigation. Plants in experiments four and five were leached with tap water every fifth watering.

For the first four experiments the following parameters were recorded: time to reach visible bud (diam.>2mm), days to flower from sowing, flower diameter (cm), total number of buds (diam.>5mm), apical and lateral bud abortion, vegetative height (cm) and total plant height measured from the media line to the uppermost leaf held parallel to the soil and to the top of the uppermost fully open flower respectively.

Experiment 1. The objective of the first experiment was to evaluate the effect of different quantum flux densities (QFD) and low temperatures on bud abortion on T.erecta cv. Moonshot. Fourteen days after sowing, the seedlings were transplanted and placed in growth

chambers at 17°C Day and 14°C Night (±2°C) and QFD of 50, 100, 150, 200 and 300 $\mu$ $Em^{-2}s^{-1}$ (±20 $\mu Em^{-2}s^{-1}$). Cool white flourescent lamps were used as the light source. Water was applied between 9:00 and 10:00 a.m. after 24, 48 and 72 hr. depending upon treatment.

A split-plot experimental design with five main plots with six plants for each sub-plot per block was used. There were three replications. The experimental design was:

| | |
|---|---|
| | A - 50±20 $\mu$ $Em^{-2}s^{-1}$ |
| Main Plots | B - 100±20 " |
| 5 Light Levels | C - 150±20 " |
| | D - 200±20 " |
| | E - 300±20 " |
| | |
| Sub-Plots | A - 100 ml/24 hours |
| 3 Water Levels | B - 100 ml/48 hours |
| | C - 100 ml/72 hours |

Experiment 2. The objectives were to evaluate the effects of higher temperatures in relation to different QFD and water regimes on apical bud abortion.

A derivative of the split-plot design, the split, split plot with three replications was used for the experiment with six plants for each sub-sub plot per replication. The design was as follows:

| | |
|---|---|
| Main Plots | A - (20°C Day, 16°C Night) ±2°C |
| 3 Temperature Levels | B - (23°C " , 19°C " ) ±2°C |
| | C - (26°C " , 22°C " ) ±2°C |
| Sub Plots | A - 250±20 $\mu$ $Em^{-2}$ $s^{-1}$ |
| 3 Light Levels | B - 300±20 " |
| | C - 350±20 " |
| Sub,Sub Plots | A - 100 ml/24 hours |
| 3 Water Levels | B - 100 ml/48 hours |
| | C - 100 ml/72 hours |

Experiment 3. The third experiment was conducted under greenhouse conditions and the objective was to study the effect of Silver Thiosulfate (STS) applications on apical bud abortion.

Seeds of T.erecta cv. Moonshot were germinated under mist. Fourteen days before transplanting, the flats were removed from the mist bench into a greenhouse environment. Twenty-one days after sowing, the seedlings were transplanted and placed under appropriate temperatures. Water application was done between 9:00 and 10:00a.m. after 24 and 48 hour intervals with 200 and 100ml of water respectively. Plants were treated with Silver Thiosulfate (STS) at 50 ppm of Silver Nitrate in Sodium Thiosulfate (Table A1). Control plants were sprayed with deionized water. In all cases ten ml of STS or water were sprayed per plant with a hand sprayer. Tween 20(0.1%) was added as a surfactant to the STS treatments. All applications were done at first visible bud stage (diam>2mm) between 5:00 and 6:00 p.m.

The next watering was after a minimum of 24 hours.

A split, split plot design with three replications was used for the experiment with six plants within each sub plot. The design configuration was as follows:

| | |
|---|---|
| Main Plots | A - 23°C Day, 19°C Night ±2°C |
| 2 Temperature Levels | B - 29°C Day, 25°C Night ±2°C |
| Sub Plots | A - 200 ml/24 hours |
| 2 Water Levels | B - 100 ml/48 hours |
| Sub,Sub Plots | A - + STS (50ppm $AgNO_3$) 10ml/plant |
| STS | B - - STS (Deionized $H_2O$) 10ml/plant |

Experiment 4. The objective of the fourth experiment was to determine the effect of exogenous ethylene applied as (2-chloroethyl)phosphonic acid (ethephon), alone or in conjunction with silver thiosulfate (STS) upon apical bud abortion.

Greenhouse temperatures were 23 Day and 17 Night(±2°C). Water was applied between 8:00-9:00a.m. and 5:00-6:00p.m. according to plant requirement. One hundred ppm ethrel (A.I. 21.3% ethephon) and 50 ppm of Silver Nitrate in Sodium Thiosulfate (Table A1) were applied as a spray to run off. Control plants were sprayed with deionized water. Tween 20 (0.1%) was used as a surfactant in all ethrel and STS sprays. All applications were done at the first visible bud stage (diam.>2mm). Plants were watered after a minimum of 24 hours.

A completely randomized design with four replications and six plants per replication was used. The design configuration was as follows:

| | | | |
|---|---|---|---|
| 2 chemicals | A - Ethrel (100ppm) 10ml/plant | | |
| | B - STS(50ppm)+Ethrel (100ppm) 2x10ml/plant | | |
| | | Application time (base time 0) | |
| | | STS | Ethrel |
| | A - Control (deionized H O) | - | - |
| | B - Ethrel (100ppm) | - | 0 |
| and 7 application | C - STS(50ppm)+Ethrel(100ppm) | 0 | 0 |
| time combinations | D - " " | - 3 | 0 |
| | E - " " | - 6 | 0 |
| | F - " " | -12 | 0 |
| | G - " " | -24 | 0 |

Experiment 5. The last experiment was conducted to determine if high temperature effects can be offset by application of silver thiosulfate. Cultural procedures were the same as previously described except that the plants were placed in a growth chamber at appropriate treatment combinations after transplanting. Environmental conditions were 31 $\pm$1°C constant and QFD 400$\pm$20 $_{\mu}$ $Em^{-2}s^{-1}$. Cool white flourescent lamps were the light source for a nine hour photoperiod.

Silver thiosulfate was applied at 50 ppm of $AgNO_3$ (Table A1) during the week before the first apical bud was observed and one and two weeks later. Ten ml of solution were applied to the foliage with a hand sprayer. Control plants were sprayed with deionized water. Tween 20 (0.1%) was used as a surfactant in silver thiosulfate treatments. Applications were made just before the dark period. Water was applied after 24 hours.

A completely randomized design with four replications and six plants per replication was used. The experimental configuration was as follows:

| | | |
|---|---|---|
| 2 substances | A - (+STS, 50ppm of $AgNO_3$) | 10ml/plant |
| | B - (-STS, deionized $H_2O$) | 10ml/plant |
| | A - Control (+1 week from visible bud) | |
| and 4 application | B - STS (-1 week " " " ) | |
| time | C - STS (+1 week " " " ) | |
| | D - STS (+2 week " " " ) | |

The following parameters were recorded: time to reach visible bud stage (diam>2mm), days to flower from sowing, days from visible bud to flower and number of apical bud abortions.

Study of Meristematic Changes. A study was conducted of meristematic changes in plants from experiments two and four. Terminal and lateral buds of randomly chosen plants in all treatments were collected at

weekly intervals from visible bud to experiment termination. Buds were collected and immediately fixed in FAA (50% ethyl-alcohol, 10% formaldehyde, 5% glacial acetic acid and 35% water). The samples were dehydrated with tertiary butyl-alcohol and infiltrated with paraplast (Johansen, 1940). Each bud was imbedded in paraplast and mounted on plastic frames. Ten micron sections were cut and fixed on slides with Haupts adhesive and 10% formaldehyde solution. The sections were stained with Safranin and Fast Green as described by Berlyn and Miksche (1976) and Sass (1958).

Analysis of the Results. The result section is divided into three parts. The first two give results of the experiments performed, while part three deals with the anatomical studies.

# RESULTS

The objectives of the first two experiments were to investigate the role of temperature (17, 20, 23 and 26°C), quantum flux densities (50, 100, 150, 200, 250, 300 and 350 $\mu Em^{-2}s^{-1}$) and water regimes (high, optimum and low) upon apical bud abortion. Experiments three, four and five provided data pertinent to the prevention of this disorder by foliar applications of silver thiosulfate (STS). The morphological, physiological and anatomical changes that occurred during apical bud abortion are presented in the last part of this section.

1. Experiments 1 and 2. Complete data are presented in Appendix B.

Days to First Bud. Plants grown in temperatures greater than 20°C and quantum flux densities above 200 $\mu Em^{-2}s^{-1}$ or under natural light, reached the first bud stage four to six weeks earlier than plants grown below 200 $\mu Em^{-2}s^{-1}$, depending on water stress. Quantum flux densities less than 200 $\mu Em^{-2}s^{-1}$ and temperatures lower than 20°C delayed the appearance and thereafter strongly inhibited the development of the first bud. The lower the light intensity the greater the inhibition regardless of water treatment.

Days to First Flower. Plants grown under quantum flux densities below 200 $\mu Em^{-2}s^{-1}$ did not flower. As quantum flux densities increased above 200 $\mu Em^{-2}s^{-1}$ and temperatures increased from 17 to 26°C, plants flowered more rapidly. Plants under low water treatments flowered earlier than plants under regular watering and high water stress.

Flower Diameter. Flower diameter was measured when the first flower was fully expanded. Temperature and water treatments had a significant effect on the size of the first flower. The result was larger flowers compared to the controls.

Vegetative and Total Height. Increasing temperatures, quantum flux densities and low water stress in all experiments increased vegetative and total plant height.

Total Number of Buds. Quantum flux densities higher than 250 $\mu Em^{-2} s^{-1}$ and temperatures above 20°C did not have an effect on bud count (Fig. 1). Temperatures of 17°C and light intensities below 200 $\mu Em^{-2} s^{-1}$ significantly reduced total bud number (Table 1).

Apical and Lateral Bud Abortion. Apical and lateral bud abortion did not occur when plants were grown at temperatures of 17 and 20°C regardless of light and water treatments (Table 1). Temperatures above 23°C significantly enhanced lateral bud abortion and above 26°C both apical and lateral bud abortion (Fig.1).

Leaf Epinasty. Epinasty was observed in plants at temperatures higher than 26°C. The apical bud subsequently aborted on these plants. Epinasty and increased apical and lateral bud abortion was also observed in plants placed under greenhouse conditions (temp>30°C and QFD>1500 $\mu Em^{-2} s^{-1}$) after termination of the experiments.

Adventitious Root Formation. Adventitious root formation occurred in low moisture stress plants under high temperatures (>26°C). Single root hairs were formed from epidermal cells along the lowest three internodes. The density and size of the roots were reduced from the lowest to the third internode.

Imperfect Flowers. A number of plants in temperatures above 26°C had small, single flowers (diam<30mm) and a partially developed flower corolla. The rest of the flower failed to develop and decayed. Imperfect flowers occurred in plants where apical and lateral bud abortion were also observed.

2. Experiments 3, 4 and 5. Complete data are presented in Appendix C.

Days to First Flower. Ethrel applications significantly delayed flowering, but applications of silver thiosulfate (STS) alone or in conjunction with ethrel had no effect on flowering when applied at or a week before visible bud (Table 4).

Total Number and Diameter of Open Flowers. Plants treated with ethrel alone had a significantly smaller number of fully open flowers and a significant reduction in flower size compared to control or silver thiosulfate treated plants. Total number of flowers and flower diameter was not significantly different from control in STS treated plants, even those treated with ethrel (Fig. 2 and 3).

Growth After Ethrel and STS Applications. Ethrel alone or in combination with silver thiosulfate resulted in taller plants than the controls. Plants treated with silver thiosulfate alone were shorter than untreated plants.

Total Number of Buds. Plants treated solely with ethrel had a significantly higher number of buds than controls and plants sprayed with silver thiosulfate and ethrel under other time combinations (Table 2 and 3). Silver thiosulfate applications at temperatures above 23°C

(Fig. 2 and 3) and water stress conditions did not significantly affect the total number of buds.

Apical and Lateral Bud Abortion. All apical buds on plants treated solely with ethrel aborted. Silver thiosulfate prevented abortion of apical and lateral buds for at least four weeks regardless of time of its application prior to ethrel treatment (exper.4) or temperature and time treatments (exper.3 and 5, tables 2 and 3).

Leaf Epinasty. Epinasty was very characteristic of ethrel treated plants and appeared within four hours after application. In older leaves, the epinastic response was permanent while younger ones gradually recovered. Plants sprayed with silver thiosulfate alone or prior to ethrel applications did not show epinasty.

Adventitious Root Formation. Adventitious roots were initiated over the whole stem on all ethrel-treated plants. Roots were formed from the epidermal cells along the whole length of the stem. Their density and size was the same along the stem and they started scenescing two to three weeks after initiation. No root formation was observed in plants where silver thiosulfate was applied alone or prior to ethrel treatment.

Imperfect Flowers. Plants treated with ethrel had a number of smaller flowers and other abnormalities such as partially developed corolla. These abnormalities were not observed on plants treated with silver thiosulfate for at least three weeks after application.

3. Bud Studies. Sections of T.erecta cv. Moonshot buds examined unde microscope showed that aborted buds were more mature than non-aborted of the same age and size. Development of mature pollen was observed in both ray and disk flowers. Marginal florets were the most mature. Abnormalities such as cell wall breakage or formation of a separation layer at the region where florets are attached to the receptacle were not observed. Cell disorganization and an irregular breakage of the cortex, vascular tissue and pith was observed where the receptacle is attached to the stem. These zones were not typical abscission zones because they appeared as region of abrupt structural weakness (Appendix D).

Table 1. The Effect of Quantum Flux Density, Temperature and Water Stress on the Total Number of Buds, Apical and Lateral Bud Abortion in T.erecta L. cv. Moonshot.

| QFD $\mu Em^{-2}s^{-1}$ | Water Treatment (3) | Total number of buds (1) | | | Apical buds aborted (1) | | | Lateral buds aborted (1) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 20°C | 23°C | 26°C | 20°C | 23°C | 26°C | 20°C | 23°C | 26°C |
| 250 | H | 4.8 | 6.6 | 8.2 | 0.0 | 0.1 | 0.5 | 1.3 | 1.5 | 3.0 |
| | O | 5.5 | 6.1 | 7.6 | 0.0 | 0.0 | 0.1 | 1.9 | 0.4 | 3.5 |
| | L | 6.7 | 5.8 | 8.0 | 0.0 | 0.3 | 0.1 | 3.3 | 2.2 | 3.9 |
| 300 | H | 5.6 | 6.5 | 5.7 | 0.2 | 0.2 | 0.0 | 1.7 | 1.5 | 2.6 |
| | O | 6.5 | 7.2 | 7.4 | 0.1 | 0.2 | 0.2 | 2.2 | 2.5 | 3.2 |
| | L | 5.1 | 7.0 | 6.7 | 0.0 | 0.1 | 0.5 | 0.2 | 2.5 | 2.5 |
| 350 | H | 5.5 | 6.8 | 6.7 | 0.1 | 0.3 | 0.1 | 1.6 | 2.5 | 3.3 |
| | O | 8.6 | 5.4 | 7.0 | 0.0 | 0.3 | 0.1 | 3.3 | 1.9 | 2.7 |
| | L | 5.2 | 7.0 | 7.7 | 0.0 | 0.0 | 0.2 | 0.0 | 1.7 | 3.9 |

Significance

| | | | |
|---|---|---|---|
| QFD | NS | NS | NS |
| Water | NS | NS | NS |
| Temperature | ** | ** | ** |
| Temp.* QFD | ** | NS | * |
| Temp.* Water | ** | NS | ** |
| QFD * Water | NS | NS | ** |
| Temp.* QFD * Water | ** | ** | ** |

(1) Mean separation within temperature by HSD (.01). Values: Total number of buds = 1.4; Apical buds aborted =0.3; Lateral buds aborted = 1.0.
(2) Significance of F: NS = Non-Significant; * = Significant at 5% level; ** = significant at 1% level.
(3) H = High, O = Optimum, L = Low.

Table 2. The Effect of Silver Thiosulfate Applications on the Total Number of Buds and Apical and Lateral Bud Abortion of *T. erecta* L. cv. Moonshot at Temperatures of 23 and 29°C.

| | Total Number of Buds (1) | | | Apical Buds Aborted (1) | | | Lateral Buds Aborted (1) | | |
|---|---|---|---|---|---|---|---|---|---|
| Temperature | STS | NO | STS | STS | NO | STS | STS | NO | STS |
| 23°C | 4.5 | 5.4 | | 0.0 | 0.0 | | 0.5 | 0.7 | |
| 29°C | 5.0 | 6.0 | | 0.0 | 0.0 | | 1.0 | 1.5 | |
| Significance: | | | | | | | | | |
| Temperature | | NS | | | NS | | | * | |
| Treatment | | NS | | | NS | | | * | |

(1) Mean separation within treatments by HSD (.05)test. Values: Lateral buds aborted = 1.2.

Table 3. Effect of Ethrel and Silver Thiosulfate Plus Ethrel Treatments at Various Time Combinations (1) on T.erecta L. cv. Moonshot at 23°C.

| Treatments | Total number of buds | Apical buds aborted (%) | Lateral buds aborted (%) | Total Number of flowers |
|---|---|---|---|---|
| 1. Control | 13.3 | 0 | 0 | 5.8 |
| 2. Ethrel | 22.1 | 100 | 0 | 3.0 |
| 3. STS+Ethrel | 16.5 | 0 | 0 | 5.6 |
| 4. " " | 15.5 | 0 | 0 | 5.4 |
| 5. " " | 18.1 | 0 | 0 | 4.7 |
| 6. " " | 16.1 | 0 | 0 | 3.3 |
| 7. " " | 20.4 | 0 | 0 | 3.4 |
| Significance Treatment | ** | ** | | * |

(1) All ethrel applications (100ppm) at zero (0) time. 50 ppm of STS applied at 0, -3, -6, -12 and -24 hrs.
(2) Data was taken 28 days after Ethrel applications.
(3) Mean separation within columns by HSD (.01). Total number of buds = 5.7; total number of flowers = 3.2.
NS = Non significant; * = significant at 5% level; ** = significant at 1% level.

Table 4. Effect of Silver Thiosulfate Application on T.erecta L. cv. Moonshot at 31°C.

| Treatments | Days to visible bud (VB) | Days to flower | Days from visible bud to flower | Apical buds aborted |
|---|---|---|---|---|
| 1. Control | 40.9 | 63.8 | 23.0 | 0.1 |
| 2. STS (1 wk before VB) | 42.9 | 64.7 | 21.7 | 0 |
| 3. STS (wk of VB) | 38.9 | 60.5 | 21.6 | 0 |
| 4. STS (1 wk after VB) | 36.4 | 56.3 | 19.9 | 0 |
| Significance Treatment | | ** | NS | * |

(1) Mean separation within columns by HSD (.05) test.
Values: Days to flower = 5.48, NS = Non significant; * = significant at 5% level; ** = significant at 1% level.

Figure 1. The effect of temperature on total number of buds and apical (ABA) and lateral bud (LBA) abortion in T. erecta L. cv. Moonshot.

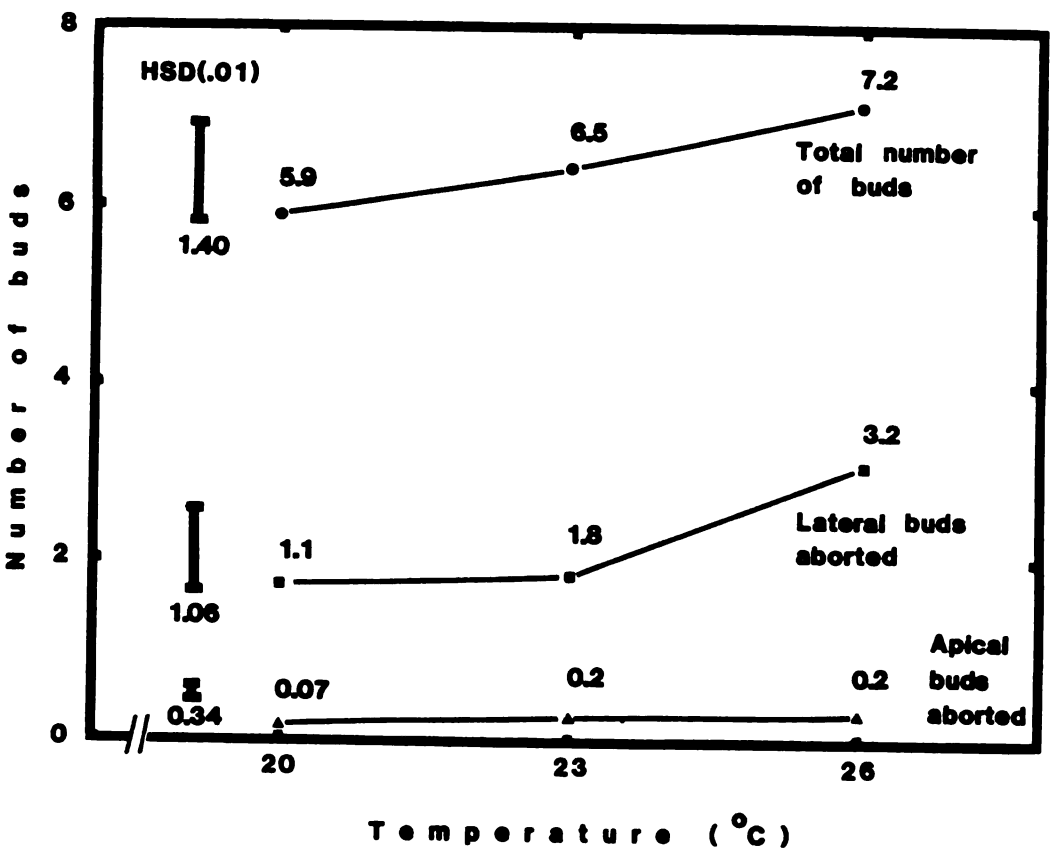

HSD(.01)
1.40
1.06
0.34
7.2
6.5
5.9
Total number of buds
3.2
1.8
1.1
Lateral buds aborted
0.2
0.2
0.07
Apical buds aborted
8
6
4
2
0
Number of buds
20
23
26
Temperature (°C)

Figure 2. The effect of ethrel (100 ppm) and STS (50 ppm of $AgNO_3$) at 23°C upon total number of buds and open flowers in T. erecta L. cv. Moonshot.

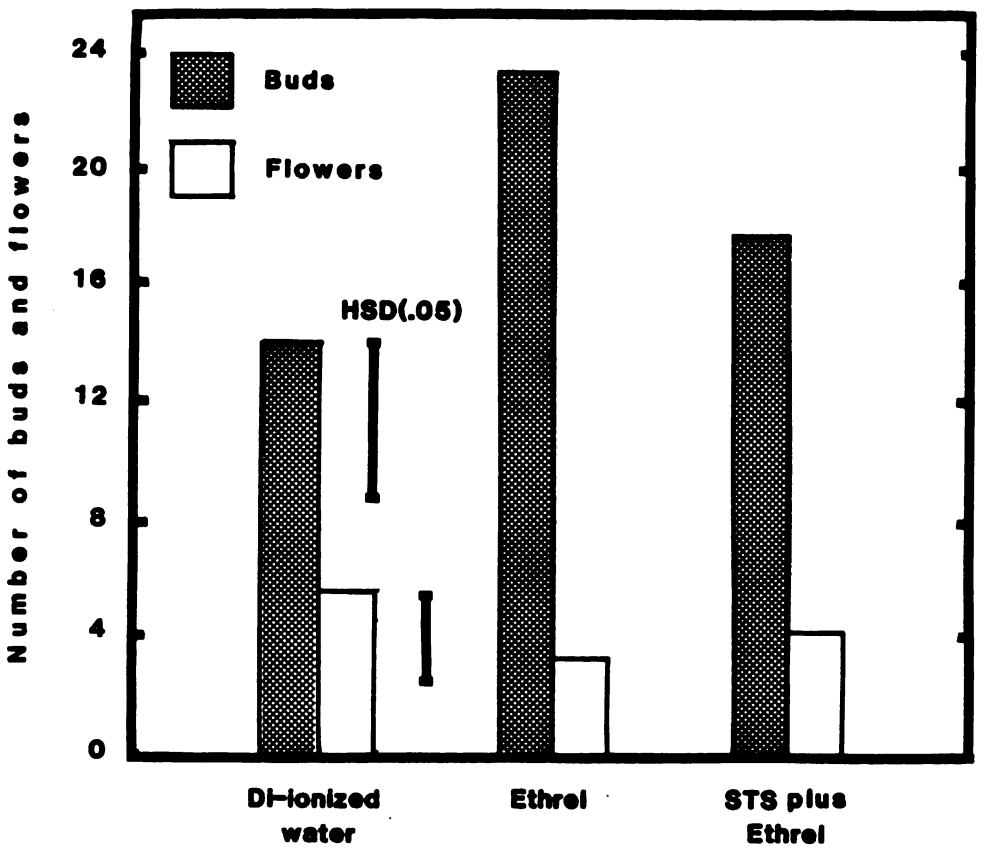
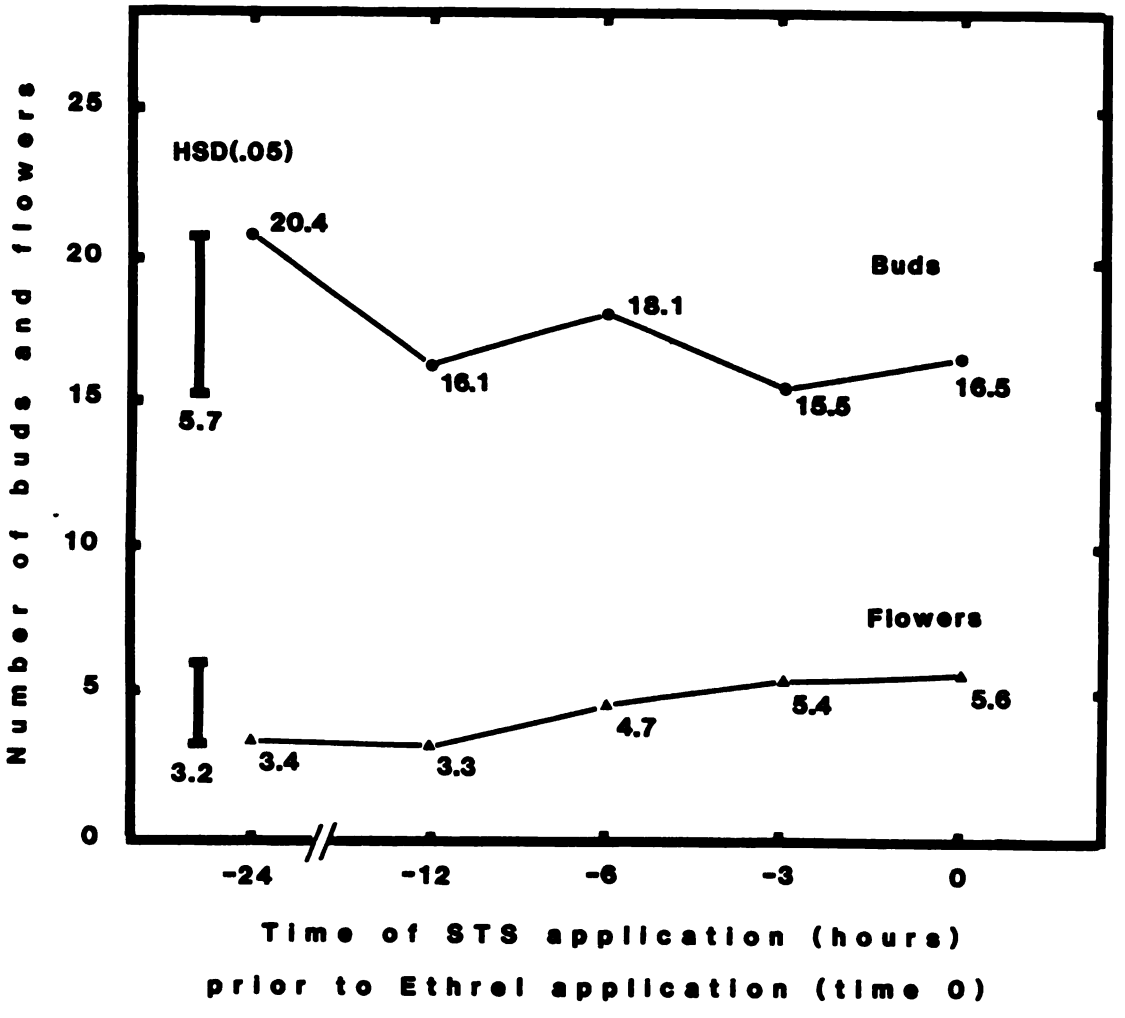

Number of buds and flowers
24
20
16
12
8
4
0
Buds
Flowers
HSD(.05)
Di-ionized water
Ethrel
STS plus Ethrel

Figure 3. The effect of STS (50 ppm of $AgNO_3$) single and combined with ethrel (100 ppm) at 23°C on total number of buds and open flowers in T. erecta L. cv. Moonshot. Time of STS application -24, -12, -6, -3 and 0 hours prior to Ethrel application (time 0).


Number of buds and flowers
25
20
15
10
5
0
HSD(.05)
20.4
18.1
16.1
15.5
16.5
Buds
5.7
Flowers
3.2
3.4
3.3
4.7
5.4
5.6
-24
-12
-6
-3
0
Time of STS application (hours)
prior to Ethrel application (time 0)

# DISCUSSION

As temperature increased from 23 to 31°C bud abortion in T. erecta L. cv. Moonshot increased. This confirms the work of Armitage (1980) showing temperatures above 30°C result in death of the flower bud in Tagetes patula L. Temperatures between 25 and 35-37.5°C greatly increase endogenous ethylene production in plants (Field, 1981 and Salveit and Dilley, 1978).

A known anti-ethylene agent, silver ion, totally prevented bud abortion in plants under environmental conditions favoring ethylene synthesis and in the presence of ethrel, an ethylene releasing compound. This inhibition of bud abortion by STS in marigolds supports the hypothesis that silver ion ($Ag^+$) is an inhibitor of ethylene action rather than ethylene synthesis (Beyer, 1976, Veen, 1979, Miranda, 198[illegible], Cameron and Reid, 1981 and 1983).

The maturity of aborted buds also indicates the involvement of ethylene in this abnormality. The ability of ethylene to promote maturity is well established. Respiration and premature fading of buds in certain ornamental plants was found to be accelerated by both ethylene and pollination (Abeles, 1973, DeMunk, 1972). According to Mayak and Halevy (1980) pollination induced the onset of the second phase of ethylene production which is characterized by an accelerated rise of ethylene synthesis.

Cell disorganization and irregular breakage of the vascular tissue of the aborted buds where the receptacle is attached to the stem tip can also be attributed to ethylene action. According to Webster (1968) these areas in bean are considered an abscission layer. Breakage of the cortex, vascular tissue and pith was present in both mature and immature aborted buds. Therefore, there may be two sites of ethylene action; one in the region where the bud receptacle and the stem tip are attached and the other within the bud.

The abortion of all apical buds in plants treated with ethrel and the subsequent accelerated outgrowth of laterals supports the hypothesis that ethylene accumulating in the apical regions moved with photosynthates (Weaver et al. 1972). When active apical buds are present, there is little photosynthate transport to lateral sites. When retardation of the apical bud occurred, nutrients and other growth factors were redirected to the laterals and subsequent growth occurred (Andersen, 1976, and Yeang and Hillman, 1981).

Leaf epinasty and adventitious root formation observed in plants with aborted buds can also be attributed to ethylene action. Similar results were observed by a number of investigators (Zimmerman and Hitchock, 1933, Zimmerman et al., 1930 and 1933, Zimmerman and Wilcoxon, 1935) when T. erecta L. plants were treated with ethylene. Silver thiosulfate totally inhibited leaf epinasty and adventitious

root formation in the presence of ethrel or environmental conditions favoring ethylene synthesis and action. On the other hand the formation of smaller and in some cases imperfect flowers could not be attributed soley to ethylene action because other factors such as genetic control and variations in environmental conditions may be involved.

From the results of these experiments we propose that unfavorable environmental conditions such as temperatures above 23°C trigger endogenous ethylene production. Ethylene accelerates maturity of the apical bud which ceases its development and finally aborts. The abortion of the apical bud results in an outgrowth of laterals which subsequently show the same abortion symptoms. Silver thiosulfate applied at 50 ppm of Silver Nitrate in Sodium Thiosulfate in early stages of bud development totally prevented bud abortion in T. erecta L. cv. Moonshot in the presence of ethrel or environmental conditions favoring ethylene synthesis and action. The use of silver thiosulfate seems commercially promising because STS at low concentrations is not phytotoxic and minimizes cost. Further work is needed to investigate possible side-effects of STS use and the potentiality of other compounds to prevent this abnormality.

# APPENDICES

# APPENDIX A

Table A1. Formula used to make the Silver Thiosulfate to control bud abortion in T. erecta L. cv. Moonshot (Miranda, 1980).

1. 50mg Silver Nitrate ($AgNO_3$) dissolved in 1/2 liter of distilled water.
2. 292mg of Sodium Thiosulfate ($Na_2S_2O_3.5H_2O$) dissolved in 1/2 liter of distilled water.
3. The Silver Nitrate ($AgNO_3$) solution was mixed in the Sodium Thiosulfate ($Na_2S_2O_3.5H_2O$) solution slowly under continuous stirring.
4. 10ml STS solution was sprayed per plant.

# APPENDIX B

Table B1. The Effect of Quantum Flux Densities and Water Regimes upon T. erecta cv. Moonshot at 17°C.

| Light $\mu Em^{-2} s^{-1}$ | Water (1) | Days to visible bud | Days to flower | Flower diam. (cm) | Total number buds | Vegetative height (cm) | Total height (cm) |
|---|---|---|---|---|---|---|---|
| | H | 81.9 | 120.0+ | 0.0 | 1.0 | 5.5 | 5.8 |
| 50 | O | 85.8 | 120.0+ | 0.0 | 1.0 | 5.0 | 5.2 |
| | L | 77.1 | 120.0+ | 0.0 | 1.0 | 4.1 | 4.8 |
| | H | 73.4 | 120.0+ | 0.0 | 1.6 | 8.1 | 9.5 |
| 100 | O | 67.5 | 120.0+ | 0.0 | 1.8 | 8.0 | 6.6 |
| | L | 65.7 | 120.0+ | 0.0 | 1.7 | 6.5 | 9.0 |
| | H | 71.4 | 120.0+ | 0.0 | 2.3 | 9.8 | 11.2 |
| 150 | O | 70.1 | 120.0+ | 0.0 | 2.3 | 8.9 | 10.9 |
| | L | 69.2 | 120.0+ | 0.0 | 2.0 | 6.6 | 9.8 |
| | H | 67.7 | 120.0+ | 0.0 | 2.3 | 9.6 | 11.0 |
| 200 | O | 68.0 | 118.2 | 0.2 | 2.6 | 9.0 | 11.1 |
| | L | 63.1 | 116.4 | 0.7 | 2.8 | 7.9 | 10.0 |
| | H | 53.6 | 114.0 | 0.1 | 3.7 | 9.9 | 12.8 |
| 300 | O | 48.5 | 103.6 | 0.3 | 3.3 | 9.2 | 13.5 |
| | L | 46.8 | 79.8 | 0.6 | 2.1 | 8.7 | 13.1 |
| HSD (.05) | | 4.5 | 8.3 | 1.6 | 0.7 | 1.1 | 1.5 |

(1) H = High, O = Optimum, L = Low

Table B2. The Effect of Quantum Flux Densities and Water Regimes upon T. erecta cv. Moonshot at 20°C.

| Treatment Light | (1) Water | Days to visible bud | Days to flower | Flower diam. (cm) | Total number buds | Lateral buds aborted | Vegetative height (cm) | Total height (cm) |
|---|---|---|---|---|---|---|---|---|
| 250 $\mu Em^{-2}s^{-1}$ | H | 43.5 | 65.5 | 6.2 | 4.8 | 1.3 | 13.4 | 18.6 |
| | O | 43.8 | 70.2 | 6.2 | 5.5 | 1.9 | 12.6 | 17.4 |
| | L | 39.1 | 53.1 | 6.7 | 6.7 | 3.3 | 11.6 | 16.1 |
| 300 $\mu Em^{-2}s^{-1}$ | H | 45.5 | 71.3 | 5.4 | 5.6 | 1.7 | 15.5 | 20.1 |
| | O | 45.2 | 73.6 | 5.6 | 6.5 | 2.2 | 14.9 | 18.7 |
| | L | 40.4 | 58.3 | 6.1 | 5.1 | 0.2 | 12.6 | 17.1 |
| 350 $\mu Em^{-2}s^{-1}$ | H | 44.4 | 71.1 | 6.0 | 5.5 | 1.6 | 15.4 | 19.9 |
| | O | 42.6 | 59.0 | 6.3 | 8.6 | 3.3 | 14.8 | 19.3 |
| | L | 38.6 | 52.7 | 6.7 | 5.2 | 0.0 | 12.1 | 16.6 |
| HSD (.01): | | 2.6 | 18.2 | | 1.4 | 1.0 | 1.2 | 1.9 |

(1) H = High, O = Optimum, L = Low

Table B3. The Effect of Quantum Flux Densities and Water Regimes upon T. erecta cv. Moonshot at 23°C.

| Treatment Light | (1) Water | Days to visible bud | Days to flower | Flower diam. (cm) | Total number buds | Apical buds aborted | Lateral buds aborted | Vegetative height (cm) | Total height (cm) |
|---|---|---|---|---|---|---|---|---|---|
| 250 $\mu Em^{-2} s^{-1}$ | H | 49.5 | 78.3 | 5.7 | 6.6 | 0.1 | 1.5 | 22.7 | 28.0 |
| | O | 53.0 | 80.3 | 5.4 | 6.1 | 0.0 | 0.4 | 17.7 | 23.6 |
| | L | 48.6 | 78.0 | 5.6 | 5.8 | 0.3 | 2.2 | 14.4 | 18.4 |
| 300 $\mu Em^{-2} s^{-1}$ | H | 46.2 | 87.1 | 3.9 | 6.5 | 0.2 | 1.5 | 13.8 | 17.8 |
| | O | 42.6 | 68.6 | 5.1 | 7.2 | 0.2 | 2.5 | 11.0 | 14.4 |
| | L | 42.3 | 64.9 | 5.6 | 7.0 | 0.1 | 2.5 | 12.5 | 16.6 |
| 350 $\mu Em^{-2} s^{-1}$ | H | 46.6 | 73.0 | 5.3 | 6.8 | 0.3 | 2.5 | 13.2 | 17.1 |
| | O | 45.0 | 74.1 | 4.8 | 5.4 | 0.3 | 1.9 | 12.2 | 15.9 |
| | L | 40.0 | 53.1 | 6.2 | 7.0 | 0.0 | 1.7 | 11.0 | 15.1 |
| HSD (.01): | | 2.6 | 18.3 | 1.7 | 1.4 | 0.3 | 1.0 | 1.2 | 1.9 |

(1) H = High, O = Optimum, L = Low

Table B4. The Effect of Quantum Flux Densities and Water Regimes upon T. erecta cv. Moonshot at 26°C.

| Treatment Light | (1) Water | Days to visible bud | Days to flower | Flower diam. (cm) | Total number buds | Apical buds aborted | Lateral buds aborted | Vegetative height (cm) | Total height (cm) |
|---|---|---|---|---|---|---|---|---|---|
| 250 $_{\mu}$ Em$^{-2}$s$^{-1}$ | H | 53.6 | 94.7 | 3.5 | 8.2 | 0.5 | 3.0 | 20.5 | 24.6 |
| | O | 53.7 | 75.8 | 6.1 | 7.6 | 0.1 | 3.5 | 17.3 | 23.1 |
| | L | 47.1 | 61.1 | 6.0 | 8.0 | 0.1 | 3.9 | 15.3 | 20.9 |
| 300 $_{\mu}$ Em$^{-2}$s$^{-1}$ | H | 44.7 | 65.8 | 5.9 | 5.7 | 0.0 | 2.6 | 13.1 | 18.0 |
| | O | 40.3 | 58.7 | 5.6 | 7.4 | 0.2 | 3.2 | 11.3 | 15.5 |
| | L | 39.6 | 61.7 | 5.0 | 6.7 | 0.5 | 2.5 | 10.4 | 15.0 |
| 350 $_{\mu}$ Em$^{-2}$s$^{-1}$ | H | 42.1 | 56.6 | 5.8 | 6.7 | 0.1 | 3.3 | 14.3 | 19.0 |
| | O | 39.7 | 56.8 | 6.0 | 7.0 | 0.1 | 2.7 | 12.9 | 17.2 |
| | L | 37.8 | 55.0 | 5.6 | 7.7 | 0.2 | 3.9 | 11.0 | 15.8 |
| HSD (.01): | | 2.6 | 18.3 | 1.7 | 1.4 | 0.3 | 1.0 | 1.2 | 1.9 |

(1) H = High, O = Optimum, L = Low

# APPENDIX C

Table C1. Experimental Values Obtained for Silver Thiosulfate and Two Water Treatments at 23 and 29°C.

| Treatment Temp. | Chem. | (1) Water | Days to visible bud | Days to flower | Flower diam. (cm) | Total number buds | Apical buds aborted | Lateral buds aborted | Vegetative height (cm) | Total height (cm) |
|---|---|---|---|---|---|---|---|---|---|---|
| 23°C | STS | H | 70.3 | 104.5 | 6.9 | 3.7 | 0.0 | 0.5 | 19.1 | 26.0 |
| | | L | 71.5 | 104.2 | 6.6 | 5.3 | 0.0 | 0.6 | 17.7 | 23.7 |
| | NO STS | H | 65.6 | 99.4 | 6.7 | 5.0 | 0.0 | 0.4 | 24.5 | 30.8 |
| | | L | 62.8 | 92.7 | 7.1 | 5.8 | 0.0 | 1.1 | 20.1 | 27.1 |
| 29°C | STS | H | 73.2 | 106.7 | 6.6 | 4.7 | 0.0 | 1.1 | 19.3 | 26.5 |
| | | L | 66.6 | 92.6 | 6.6 | 5.3 | 0.0 | 1.0 | 17.3 | 24.6 |
| | NO STS | H | 76.6 | 107.0 | 5.3 | 5.8 | 0.0 | 1.3 | 22.9 | 29.0 |
| | | L | 68.4 | 95.2 | 6.1 | 6.2 | 0.0 | 1.8 | 18.3 | 24.0 |
| HSD (.05): | | | 5.6 | 6.1 | 1.0 | 2.3 | 0.2 | 1.2 | 2.1 | 2.5 |

(1) H = High, L = Low

Table C2. Experimental Values Obtained for Ethrel and Combined Silver Thiosulfate and Ethrel[1] Treatments at Various Time Combinations at Temperatures 23°C.

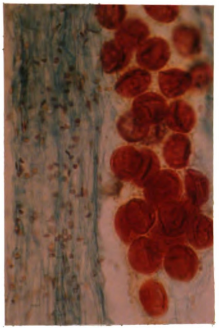
| Treatments[2] | Days to visible bud | Days to flower | Flower diam. (cm) | Total number of buds | Apical buds aborted (%) | Lateral buds aborted (%) | Vegetative height (cm) | Total height (cm) | Veg. gr.% after applic. | Total number of flowers |
|---|---|---|---|---|---|---|---|---|---|---|
| 1. Control | 54.7 | 86.4 | 8.0 | 13.3 | 0 | 0 | 29.2 | 38.6 | 20.7 | 5.8 |
| 2. Ethrel | 52.5 | 98.5 | 6.1 | 22.1 | 100 | 0 | 30.1 | 39.1 | 26.7 | 3.0 |
| 3. STS+Ethrel | 54.4 | 86.0 | 7.2 | 16.5 | 0 | 0 | 30.7 | 38.2 | 27.0 | 5.6 |
| 4. " " | 56.7 | 88.6 | 7.4 | 15.5 | 0 | 0 | 32.5 | 40.3 | 27.8 | 5.4 |
| 5. " " | 56.5 | 89.1 | 7.4 | 18.1 | 0 | 0 | 30.4 | 38.0 | 28.0 | 4.7 |
| 6. " " | 58.7 | 95.2 | 7.1 | 16.1 | 0 | 0 | 30.2 | 37.9 | 28.2 | 3.3 |
| 7. " " | 57.3 | 91.6 | 7.5 | 20.4 | 0 | 0 | 31.0 | 38.8 | 27.9 | 3.4 |
| HSD (.01): | 5.0 | 7.2 | 1.3 | 5.7 | | | | | 4.3 | |

(1) Ethrel was applied at 100 ppm and STS at 50 ppm.
(2) All ethrel applications at zero (0) time. STS applied at time 0, -3, -6, -12 and -24 hours for the treatments 3, 4, 5, 6 and 7 respectively.
(3) Data was terminated twenty eight days after STS applications.

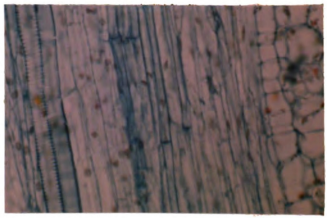
# APPENDIX D

Figure D1. Morphological changes in apical and lateral aborted buds in T. erecta L. cv. Moonshot.

a. Mature pollen grain in aborted buds (60x).
b. Normal vascular tissue and cells in non-aborted buds (60x).
c. Cell disorganization and irregular breakage of vascular tissue at the region where the receptacle attaches to the stem in aborted buds (60x).
d. Cell disorganization and irregular breakage of vascular tissue at the region where the receptacle attaches to the stem in aborted buds (60x).



a



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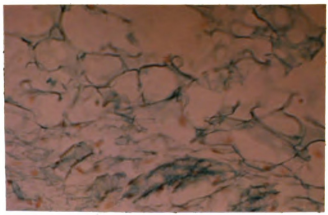

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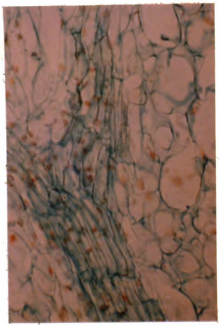

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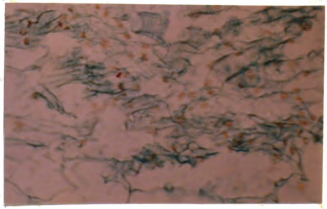

d

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