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DWARF PLANTS PRODUCED DIRECTLY FROM SEEDS TREATED WITH GROWTH RETARDANTS AND INDIRECTLY FROM SEEDS PRODUCED BY PLANTS TREATED WITH GROWTH RETARDANTS

BY

JANICE L. ANTHONY

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE

IN

PLANT AND SOIL SCIENCE

UNIVERSITY OF RHODE ISLAND

1981

MASTER OF SCIENCE THESIS

OF

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ABSTRACT

Many annual bedding plants are overly tall with sparse, pale foliage. Plant growth retardant chemicals commonly correct these undesirable characteristics. A method of producing dwarf plants by seed treatment with growth retardants could be useful to seed producers, commercial growers and home gardeners.

To determine the feasibility of producing dwarf plants by treating seeds with retardants, seeds were treated directly with aqueous, acetone or talc formulations of retardants, and indirectly by treatment of plants producing seed. The retardants SADH (N,N-dimethylamino succinamic acid), CCC ([2-chloroethyl] trimethylammonium chloride), Amo-1618, (4-hydroxy-5-isopropyl-2-methylphenyl trimethylammonium chloride, 1-piperidine carboxylate), and Ancymidol (α-cyclopropyl-α-(p-methoxyphenyl)-5-pyrimidine methanol) were used to treat seeds of marigold (Tagetes erecta L.), salvia (Salvia splendens Sello ex Nees), and petunia (Petunia hybrida Vilm.). Seeds were germinated and plants were grown to maturity. SADH, CCC and Ancymidol were also applied to marigold, salvia and petunia plants. Since inhibition of internode elongation is the primary effect of retardants, height measurements were taken to evaluate the effectiveness of all treatments.

The results of treatment of over 5,000 plants show that Ancymidol is clearly more effective than SADH or CCC

in inhibiting internode elongation of marigold, salvia and petunia plants. Drench applications retarded growth more than sprays. In some cases retardant treatment stimulated growth.

The inhibitory effect of retardant treatment is present one month after treatment and at flowering. Inhibition is generally maintained in the field. Amendment of Ancymidol mixed with ion exchange resin to the growing medium is also an effective method of controlling height of marigold, salvia and petunia plants in the greenhouse and in the field.

The results of treatment of over 3,000 seeds indicate that although few treatments inhibited internode elongation in plants grown from treated seeds, direct seed treatment with aqueous solutions of Ancymidol may be an effective method of controlling height of some bedding plants. Acetone seed treatments increased lateral branching in plants grown from treated seeds, but did not retard growth. Talc seed treatments did not inhibit growth of plants grown from treated seeds. Germination was delayed and percent germination was reduced by high concentrations of retardants applied to seeds.

With few exceptions, indirect seed treatment by treatment of parent plants was an ineffective method of inhibiting growth of second generation plants. However, several treatments with Ancymidol inhibited growth of the progeny of marigold and petunia plants, indicating that

further work with Ancymidol is warranted.

Retardant treatments of plants and seeds inhibited growth more in summer than in winter, probably because retardant action is dependent on the rate of gibberellin (GA) synthesis, which is higher in summer than in winter. Similarly, retardant treatments were more effective on young plants than on mature plants, and young plants have higher rates of GA synthesis than mature plants.

Since retardant inhibition of growth is influenced by light intensity and duration, there may be an interaction between retardants and phytochrome. Further work on the seasonal effects of retardants on phytochrome levels and activity is indicated.

ACKNOWLEDGEMENTS

I wish to express my appreciation to my major professor, Dr. William R. Krul, for his assistance in carrying out this research. I would also like to thank him for the time and effort devoted to critical review of this manuscript.

I am also grateful to Dr. Richard J. Shaw for his part in planning this research and in providing me with greenhouse space and supplies which facilitated my work.

Special thanks also go to Dr. Luke S. Albert for many helpful suggestions and for review of this thesis.

Grateful appreciation is also extended to John Bartlett for his technical assistance and to Prof. J. Lincoln Pearson and Dr. Robert E. Gough for their support and encouragement.

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INTRODUCTION

The bedding plant industry has grown dramatically in recent years due to increased interest in garden flowers of all kinds. However, many annual bedding plants are unsuitable for home display due to excessive heights, overly long stems with few leaves or unsightly pale foliage. The production of plants without these characteristics would be valuable to consumers and commercial producers. One approach to the production of more attractive plants is the production of new dwarf genetic varieties. However, genetic selection is a time-consuming process. A short term solution to the problem may be treatment of plants or seeds with plant growth retardants. The research presented in this paper addresses the second approach to the problem of production of dwarf plants.

Three genera of annual bedding plants were chosen for this study. 'Burpee's First Whites' marigold was chosen because it has pale foliage on long stems, characteristics commonly corrected by growth retardant treatment. 'Red Pillar' salvia was chosen because it was shown by Cathey (6) to be responsive to several growth retardants. 'Pink Cascade' petunia was chosen because it has a trailing growth habit and because Ball Seed Co. has expressed an interest in the production of a dwarf petunia.

The chemicals used for plant treatments were SADH, CCC and Ancymidol. Amo-1618, SADH, CCC and Ancymidol

were used to treat seeds.

This study was undertaken to determine the feasibility of treating bedding plants and seeds of bedding plants with growth retardants for the production of dwarf plants. The goals of the study were to determine, for both plants and seeds, the best chemical treatment for maximum control of internode elongation. The best method of application of retardants, the best developmental stage for retardant application to retard growth of plants and their progeny, and the longevity of the inhibitory effect of retardant treatment.

To achieve these goals experiments were done with plants and with seeds. A drench experiment was carried out with plants to determine the response of the three genera to retardant treatment. Plants were also treated with sprays, drenches and soil amendments to determine the best method of application of retardants. Plants were treated and grown in the field to determine the longevity of retardant treatment. Plants were treated at three developmental stages to determine the best stage for treatment.

Seeds were treated with aqueous, acetone and talc formulations of retardants to determine the best method of treating seeds. Percent germination and rate of germination of treated seeds were noted. Seeds were also collected from treated plants. The collected seeds were germinated and the resulting plants were grown to maturity

to determine the inhibitory effect of retardant treatment on the progeny of treated plants.

Height measurements were used to determine inhibition, since the primary effect of growth retardant treatment is inhibition of internode elongation.

LITERATURE REVIEW

Several reviews on the effects of growth retardants have been published, notably those of Cathey (5,6), Lang (38) and Sachs and Hackett (72). This review will be limited to a discussion of Amo-1618, Phosfon, CCC, SADH and Ancymidol, and will emphasize work with greenhouse crops and bedding plants.

Plant growth retardants are traditionally defined in terms of what they do, not what they are. Chemically, they represent many different classes of compounds which have the common effect of reducing plant height. Sachs and Hackett (72) cite three mechanisms of height control by chemicals: terminal bud destruction, inhibition of internode elongation, and reduced apical control. Growth retardants control height by the inhibition of internode elongation.

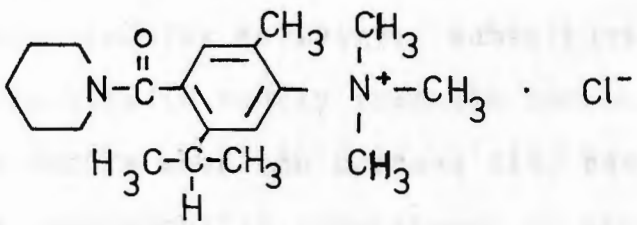
Much remains to be learned about the biochemical action of growth retardants. In general they appear to interfere with the synthesis and/or action of plant hormones. It has been suggested that they alter the ratios or levels of naturally occurring hormones (59), interfere with the synthesis and activity of gibberellic acid or auxin (70,74,89), alter CO_2 assimilation (27) or influence membrane permeability (85). Retardants elicit an array of responses which are more easily described than explained, and speculation about their biochemical action is ahead of

knowledge. It seems unlikely that retardants alter or cause only a single biochemical response since many factors are involved in growth and development.

Chemicals

Amo-1618

In 1949 a quarternary ammonium compound was found to retard stem elongation in snap beans (Phaseolis vulgaris L.). It was designated Amo-1618 (also known as ACPC) and has the following structure:



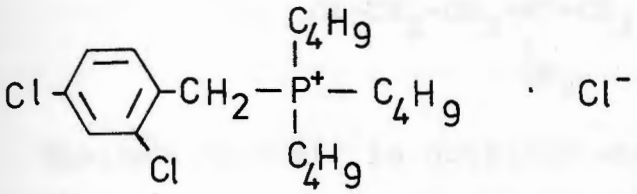
The terpene ring, the quarternary and amide nitrogens and the halide ion are crucial for activity. Amo-1618 was active on a very limited number of plant genera.

Amo-1618 reduces cell division in the subapical meristem of chrysanthemum (74). The inhibitory effect is prevented when GA is applied with Amo-1618. Amo-1618 therefore acts as a GA antagonist in the regulation of the developing shoot by the subapical meristem.

Amo-1618 and CCC are effective in blocking the incorporation of mevalonic acid into GA in pea (Pisum sativum L.) (91) and in the fungus Gibberella fujikuroi (29). GA precursors accumulate in treated tissue.

Phosfon

In 1955 several phosphonium compounds were found to reduce internode elongation in cucumber (Cucumis sativus L.). The most active of these compounds was Phosfon (CBBP) with the following structure:



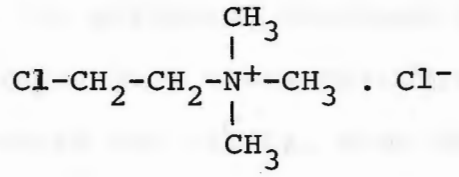
The quarternary phosphonium and the three butyl groups are required for activity. Substitution of any butyl group results in nearly inactive compounds. Maximum activity occurs when the benzene ring has a small, nonionizable, nucleophilic substituent in the number four position. Phosfon was active on many plants, including those responsive to Amo-1618.

Phosfon treatment of 'Georgia' Easter lily (Lilium longiflorum Thunb.) reduced stem strength by decreasing wall thickening of schlerencymatous cells. Phosfon inhibited DNA synthesis in apical and subapical meristems of chrysanthemum, resulting in inhibition of internode elongation and internode formation (74). Both Phosfon D (phosphonium cation) and Phosfon S (ammonium cation) block the formation of kaurene, a GA precursor, from geranylgeranyl pyrophophate (12).

CCC

In 1960 a new group of quarternary ammonium compounds,

the choline analogs, were found to be effective in reducing plant height. The most active of these compounds was chlorocholine chloride (CCC, Cycocel, Chlormequat) which has the following structure:

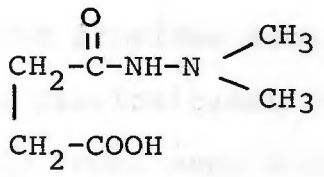


Maximum activity is obtained when the carbon chain is two carbons long with a small, nonionizable, nucleophilic substituent. The trimethylammonium cation is imperative for activity. CCC was found to be active on many woody and herbaceous plants, including most plants responsive to Amo-1618 and Phosfon.

C^{14} from labelled CCC has been found in choline (75), 17 amino acids, citric and malic acids, and CO_2 (33). Reid and Crozier (70) report that CCC increased endogenous GA levels in pea seedlings without stimulating growth. However, CCC has also been reported to block GA synthesis (69).

SADH

In 1962 a wide range of food crops and ornamental plants was found to be responsive to N-dimethylamino succinamic acid (SADH, Alar, B-9, B-995, Daminozide). The succinamic acids are structurally different from the other growth retardants. SADH has the following structure:

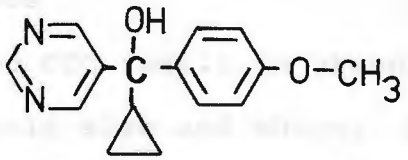


SADH has been the preferred chemical for translocation studies. It is readily transported in the xylem and phloem of both monocots and dicots, even though monocots are generally insensitive to the chemical (56). SADH moves in both the apoplast and symplast and concentrates in meristematic areas. SADH treatment may cause leakage of vacuolar substances.

The mode of action of SADH has not been fully explained. SADH inhibits the conversion of tryptamine to indoleacetaldehyde, a precursor of the auxin indole acetic acid (IAA) (68), but also increases IAA oxidase activity (25). It is not clear whether the retardant effect is related to an inhibition of auxin synthesis or an enhancement of auxin breakdown, or a combination of both.

Ancymidol

Ancymidol (A-REST, El 531), introduced in 1972, is active on a broad range of plants. It has the following unusual structure:



Ancymidol is the most active of the major growth retarding chemicals and provides excellent results on a variety of commercial floricultural crops (20,41,79,88). In a 1975 study Cathey found many more plants responsive to Ancymidol than to Amo-1618, Phosfon, CCC or SADH (6).

Ancymidol is rapidly absorbed by leaves, but uptake is faster by roots (89). Drench treatments of Ancymidol may cause slight changes in flower color, and flowering may be advanced or delayed (52). Cathey (6) found Ancymidol and GA to be mutually counteractive. Leopold (42) reported that Ancymidol is antagonistic to GA only in growth events stimulated by GA, not in nongrowth functions such as GA-induced deferral of senescence and stimulation of amylase production in seeds. He suggests that Ancymidol may inhibit reactions which occur following GA synthesis. In contrast, Ancymidol has recently been reported to block the synthesis of GA by inhibiting the oxidation of kaurene to kaurenoic acid (15).

Secondary Effects

The predominant effect of growth retardants is an overall reduction of plant height, but other useful responses also deserve mention.

Greening of Leaves

Amo-1618 and CCC result in greening of leaves without alteration of their size and shape. SADH causes greening only in mature tissue, and Ancymidol generally

causes greening only at high concentrations. SADH treatment results in an increase in chlorophyll per unit leaf area in apple (Malus sp) (27). Leaf greening is a retardant effect, not a nutritional effect (76).

Anatomical Changes

SADH treatment results in increased stomata number in blueberry (Vaccinum corymbosum L.) (23). SADH treatment results in decreased intercellular spaces in tomato (Lycopersicon esculentum Mill.) (69). In marigold, SADH treatment results in denser foliage, wider leaflets and fewer intercellular spaces (51). Similar anatomical changes have been reported in petunia (41), chrysanthemum and poinsettia (Euphorbia pulcherrima Willd.) (7). Retardant treatment results in reduced root and top growth of tall fescue (Festuca arundenacea Schreb.) and Kentucky bluegrass (Poa pratensis L.) (21).

Stem Strength

CCC treatment results in increased stem strength of carnation (Dianthus caryophyllus L.) when applied during low light seasons (39). Treatment with phthalamides, a new group of retardants, results in stem stiffness in tomato (47). Amo-1618 treatment results in increased stem diameter in beans, due to increased cell produciton in the cambium (5). However, Joiner et al. (34) and Cathey (6) report that retardants fail to increase stem strength or reduce stem length of most house plants.

Root Systems

CCC treatment inhibits rooting of herbaceous cuttings (67) and reducestuberous root formation in dahlia (Dahlia pinnata Cav.) (63). Lateral root growth of lupine (Lupinus luteus L.) was inhibited by CCC (87). Amo-1618 delayed rooting of chrysanthemum but the inhibitory effect was outgrown at flowering. Elkins (21) showed that top and root growth of Kentucky bluegrass was inhibited by nine retardants. Ancymidol treatment resulted in reduced top growth of tall fescue without interfering with root growth. SADH enhanced rooting of herbaceous cuttings (67) and protea (Protea neriifolia R. BR.) (14) and increased tuberous root formation in dahlia (63).

Flowering

Stuart (80) reported that CCC and Phosfon cause flower bud initiation in azalea (Rhododendron obtusum Lindl.). He suggested that suppression of growth may cause an accumulation of photosynthate which favors flower initiation. Low temperature normally promotes flowering in broccoli (Brassica oleracea L.), but Fontes and Ozbun (22) showed that SADH reduced low temperature flowering. They hypothesize that the inhibition is caused by reduced cell division. SADH promoted flowering in apples (90) but had no effect on flowering in raspberry (Rubus idaeus L.) (13) or bleeding heart (Dicentra spectabilis L.) (46). Retardants may cause changes in flower color in herbaceous

plants (52,63) and may delay or accerlerate anthesis.

Fruit Set and Crop Yield

Read and Fieldhouse (64) used SADH to increase yield and control timing of tomato. Edgerton, et al. (19) reported that SADH treatment resulted in increased fruit set in apple. Strawberries (Fragaria virginiana X chelo-ensis) treated with CCC or SADH developed more crowns per plant, but no changes in yield were observed (73). SADH reduced berry size and cluster length in grape (Vitis vinifera L.) (83).

Nutrient Uptake and Accumulation

Joiner et al. (34) showed that Ancymidol and fertilizer act independently on the growth of Dieffenbachia. However, SADH treatment resulted in increased calcium uptake and accumulation in apple seedlings (31). CCC and SADH treatment resulted in increased N,P, and Mg accumulation but decreased K uptake in peas (1) and tomatoes (37). Cathey (5) mentions other studies on nutrient uptake.

Environmental Stresses

Plants treated with growth retardants develop increased resistance to environmental stresses. Ancymidol reduced pollution injury in 'Annette Hegg' poinsettias by causing stomatal closure in immature leaves (6). SADH increased the tolerance of petunias to SO_2 and O_3 fumigation (84). Cathey and Heggestad (7) found that Phosfon and SADH

reduced pollution damage to petunia but CCC and Ancymidol, which did not retard growth, had no protective effect. Phosfon and SADH limited penetration of pollutants into leaves by inducing increased thickness of cell walls and partial closure of stomata. There are related reports that retardants increase drought resistance of tomato (37) and hibiscus (3) and there have been investigations into the effects of growth retardants on salt tolerance (30) and cold hardiness (13,28). Retardants are thought to reduce insect populations on treated plants by interfering with their ability to reach adulthood (86) or reproduce normally (82).

Seed Treatments

Most work with growth retardants has been concentrated on the action of various chemicals on the appearance of plants (34,41,46,81) but some attention has been paid to the effect of retardant chemicals on biochemical processes (16, 17,29), morphology (21,27), and anatomy (7,51,84). Few researchers have used annual bedding plants as test plants, and comparatively little work has been done on the effect of growth retardants or even growth regulators on plants grown from treated seeds (4,10,24,55,58,60,62).

The idea of seed treatment is not new. In 1963 penetration of wheat seeds (Triticum L.) by the insecticide DDT was reported (54). In 1968 it was reported that wheat seeds could be dehydrated during the first 24 hours of germina-

tion and still grow normally on rehydration (11). Thus seeds could be treated with chemicals in water or organic solvent and dried after treatment without adverse effects on germination. Materials which have been used to treat seeds, either alone or as carriers for other compounds, include water (24), dichloromethane (60), acetone (53), benzene, chloroform, ether (54) and talc (42). Growth regulators have been applied to seeds in water and in organic solvents (4,24,36,55,58,60,62), and treatment of seeds with growth retardants has been reported (10).

Growth retardant treatment of seeds may alter percent germination. SADH and Phosfon (tributyl-2,4-dichlorobenzylphosphonium chloride) decreased germination of several weed seeds (10). Increased germination of fodder crops following seed treatment with SADH, CCC and Phosfon has been reported (92).

Growth retardant treatment of seeds may affect germination in other ways. SADH was applied with gibberellic acid to replace the light requirement in germination of celery seed (Apium graveolens L.) (60).

The mobilization of retardants into flowers and seeds indicates that indirect treatment of seeds by treatment of the parent plant may be an effective method of dwarfing plants. It has been shown that when 'McIntosh' apple trees (Malus pumila Mill.) are treated with SADH, the chemical is found in the seeds after 24 hours (18). In chrysanthemum (Chrysanthemum morifolium Ramat.) the final sink for

Ancymidol is the flowers (61). Seed has been treated with GA indirectly through the parent plant (55), but there are as yet no reports of successful indirect treatment of seed with growth retardants.

MATERIALS AND METHODS

Plant Materials

Seeds of 'Burpee's First Whites' marigold, 'Red Pillar' salvia and 'Pink Cascade' petunia were obtained from Burpee Seed Co., Warminster, Pennsylvania and Ball Seed Co., West Chicago, Illinois. Seeds to be grown to maturity were germinated in Redi-Earth or Jiffy Mix, commercial peat moss and vermiculite mixtures. One month after germination seedlings were transplanted into Redi-Earth, Jiffy Mix or peat moss and vermiculite (1:1, v/v) amended with lime to bring the pH to approximately 6.0. All greenhouse grown plants were maintained at approximately 70°F day temperature and 60°F night temperature. Plants were grown under 60 watt incandescent lights with a 16 hour photoperiod during the winter to extend the photoperiod and to minimize seasonal light variation. A 20-20-20 fertilizer was applied weekly at the rate of approximately 500 ppm nitrogen, and plants were watered as necessary.

Chemicals

Crystalline SADH, CCC and Amo-1618 were obtained, respectively, from Aldrich Chemical Co., Milwaukee, Wisconsin; Sigma Chemical Co., St. Louis, Missouri; and Rainbow Color and Chemical Co., Northridge, California. A concentrated liquid formulation of Ancymidol was obtained from Griffin Greenhouse Supply Co., Tewksbury, Massachusetts, or donated by Eli Lilly and Co., Indianapolis, Indiana. Baker analy-

tical grade acetone was obtained from Arthur Thomas Co., Philadelphia, Pennsylvania and Dowex 1-X8 ion exchange beads were obtained from Bio-Rad Laboratories, Richmond, California.

Plant Treatments

Growth retardants were applied to marigold, salvia and petunia plants as soil drenches, foliar sprays or soil amendments. Since insufficient Amo-1618 was available for use in plant treatments, Amo-1618 was used for seed treatments only.

Drench Treatments

Several features were common to all soil drench treatments. Marigold, salvia and petunia plants were grown in 4" plastic pots. A single 50 ml drench treatment was applied to each plant. SADH and CCC were applied at rates of 10, 100, or 1000 ppm. Ancymidol was applied at rates of 1.32, 13.2 or 132 ppm. Distilled water was used for controls. Drenches were applied when soil was moist but not wet and an effort was made to avoid chemical contact with leaves. Height measurements were taken to the nearest centimeter, from the soil line to the last distal leaf. Three drench experiments were carried out:

1. Cultivar Response Experiment

Drench treatments of SADH, CCC or Ancymidol were applied to plants approximately two weeks after transplanting to determine whether growth would be retarded. Marigold

plants were approximately 10 cm tall and salvia and petunia plants were approximately 5 cm tall. Ten plants of each genus were used for each treatment. Height measurements were taken after one month.

II. Field Study

A field study was carried out to determine whether internode elongation inhibition was maintained under field conditions. Ten plants of each species were used for each treatment. Soil drenches were applied to potted plants. Marigold plants were approximately 10 cm tall and salvia and petunia plants were approximately 5 cm tall. Height measurements were taken one month after treatment. Plants were transplanted into the field and height measurements were taken after one month in the field. Seed from treated plants was collected, sown and grown in the greenhouse. Height measurements were taken at flowering to determine whether internode elongation would be inhibited in the next generation.

III. Treatment of Parent Plants

Plants were treated at three stages of development to determine whether developmental stage at treatemnt affected internode elongation in progeny of treated plants. Stage I plants were treated approximately two weeks after transplanting. Stage I marigold plants were approximately 10 cm tall, stage I salvia and petunia plants were approximately 5 cm tall. Stage II refers to large plants which have

not produced visible flower buds. Stage II marigold plants were approximately 35 cm tall, stage II salvia plants were approximately 25 cm tall, and stage II petunia plants were approximately 30 cm tall. Stage III refers to plants with visible flower buds. Stage III plants were slightly taller than stage II plants.

Three plants of each species were used for each treatment. Height measurements were taken at flowering. Height measurements of second generation plants were also taken at flowering.

Spray Treatments vs. Drench Treatments

Foliar sprays or drenches were applied to plants approximately two weeks after transplanting to determine the most effective method of applying growth retardants. Marigold plants were approximately 10 cm tall. Salvia and petunia plants were approximarely 5 cm tall. SADH and CCC were applied at 1000 ppm. Ancymidol was applied at 13.2 ppm. Distilled water was used for controls. Sprays were applied to runoff with a hand sprayer, on abaxial and adaxial leaf surfaces. Ten plants of each species were used for each treatment. Measurements were taken one month after treatment.

Ion Exchange Resin Treatments

Ancymidol was mixed with ion exchange resin and amended to the growing medium to determine whether internode

elongation would be inhibited. An excess of concentrated Ancymidol (246 ppm) was thoroughly mixed with Dowex 1-X8 anion exchange resin beads, chloride form. The mixture was poured into a Buchner funnel lined with one sheet of Whatman #1 filter paper. The excess solution was filtered off with an aspirator. Drained beads were spread on two sheets of filter paper in glass petri dishes and air dried. Beads were then mixed with Redi-Earth and added to 3" peat pots at rates of 0, 100, 250, 500 or 1000 mg per pot. Uniform marigold, salvia and petunia seedlings were transplanted into the treated growing medium and grown in the greenhouse. Height measurements were taken one month later. Plants in peat pots were then transplanted into an outdoor garden plot and height measurements were taken after a second month to determine whether the inhibitory effect would be maintained under field conditions. Five plants of each genus were used for each treatment.

Seed Treatments

Growth retardants were applied directly to seeds in aqueous, acetone or talc formulations. Seeds were treated indirectly by treatment of parent plants.

Direct Seed Treatments -

Several methods of direct seed treatment were examined to determine which, if any, were effective in dwarfing plants grown from treated seeds. Some features were common to all treatments. After treatment seeds were germinated

in petri dishes on one sheet of Whatman #1 filter paper moistened with distilled water which was replenished whenever necessary. Germination counts were taken daily to determine rates of germination and percent germination. Germinated seeds were discarded daily. Ten seeds of each genus were used for each treatment.

A second set of treated seeds was sown and grown in the greenhouse to evaluate the effect of seed treatment on the height of mature plants. Height measurements of plants grown from treated seeds were taken at flowering. Ten seeds of each genus were used for each treatment.

I. Aqueous Seed Treatment

Aqueous solutions of SADH, CCC and Amo-1618 were applied to dry seed at rates of 10, 100 or 1000 ppm. Ancymidol was applied at 1.32, 13.2 or 132 ppm. Dilutions were made from concentrated stock solutions, and distilled water was used for controls. Five ml of solution was added to 50 mm plastic petri dishes containing one sheet of Whatman #1 filter paper and 10 marigold, salvia or petunia seeds. Seeds were soaked in the dark for 24 hours at room temperature or 48 hours at approximately 4°C.

II. Acetone Seed Treatment

Acetone treatments were carried out as described for aqueous treatments with the use of a distilled water and an acetone control. Salvia seeds were treated for one hour at room temperature because longer treatments prevented

germination. Marigold and petunia seeds were treated for 24 hours at room temperature.

Amo-1618 and CCC are not soluble in acetone so each was first dissolved in 5 ml of distilled water to which acetone was added to make 100 ml of stock solution. Fifty ml of acetone was added to 50 ml of concentrated (264 ppm) Ancymidol to make the stock solution. Dilutions were made from stock solutions to the concentrations used for aqueous treatments. Glass jars were used for treating seeds since acetone partially dissolves plastic.

III. Talc Seed Treatment

Talc formulations were made by thoroughly mixing 25 ml of each acetone solution of retardant with 25 g of talc and air drying the mixture to powder. In addition to the concentration of solutions used for aqueous seed treatment a 264 ppm Ancymidol solution was also mixed with talc and dried to powder. Distilled water and talc alone were used for controls.

Seeds were mixed with an excess of talc, gently removed to avoid loss of the talc coating on seeds, and immediately germinated or sown.

Indirect Seed Treatment -

Seed was treated indirectly by treatment of parent plants to determine whether height of second generation plants would be reduced. Parent plants were treated with drench solutions of growth retardants as described for the

treatment of parent plants for the field study.

Seed was collected form treated plants, sown and grown in the greenhouse. Height measurements were taken at flowering.

Statistical Analysis

Each experiment was replicated twice with the exception of the experiment involving treatment of parent plants at three stages of development and the field study, which were carried out only once. Replicates were treated concurrently except in the ion exchange resin experiment, in which replicates were treated three days apart. Completely randomized designs were used for all experiments, according to Little and Hills (44). Standard error was calculated for each treatment which was replicated twice. Standard deviation was calculated for experiments carried out only once.

RESULTS

Plant Treatments

Growth retardants were applied to marigold, salvia and petunia plants as soil drenches, foliar sprays or soil amendments.

Drench Treatments -

A 50 ml soil drench was applied to each plant. SADH and CCC were applied at rates of 0, 10, 100 or 1000 ppm. Ancymidol was applied at rates of 0, 1.32, 13.2 or 132 ppm. Three types of drench treatments were examined:

I. Cultivar Response

Soil drenches of SADH, CCC or Ancymidol were applied to marigold, salvia and petunia plants approximately two weeks after transplanting to determine whether internode elongation would be inhibited. Height measurements were taken one month after treatment.

Marigold: SADH did not reduce internode elongation in marigold, and 100 ppm SADH stimulated growth (Fig. 1). Growth was retarded by CCC only at 1000 ppm. Internode elongation was inhibited following treatment with 1.32 and 13.2 ppm Ancymidol. Treatment with 132 ppm Ancymidol was toxic.

Salvia: SADH and CCC did not reduce internode elongation in salvia (Fig. 1). Height was slightly reduced by Ancymidol applied at 1.32 ppm, and height was greatly reduced at 13.2 ppm. Treatment with 132 ppm was

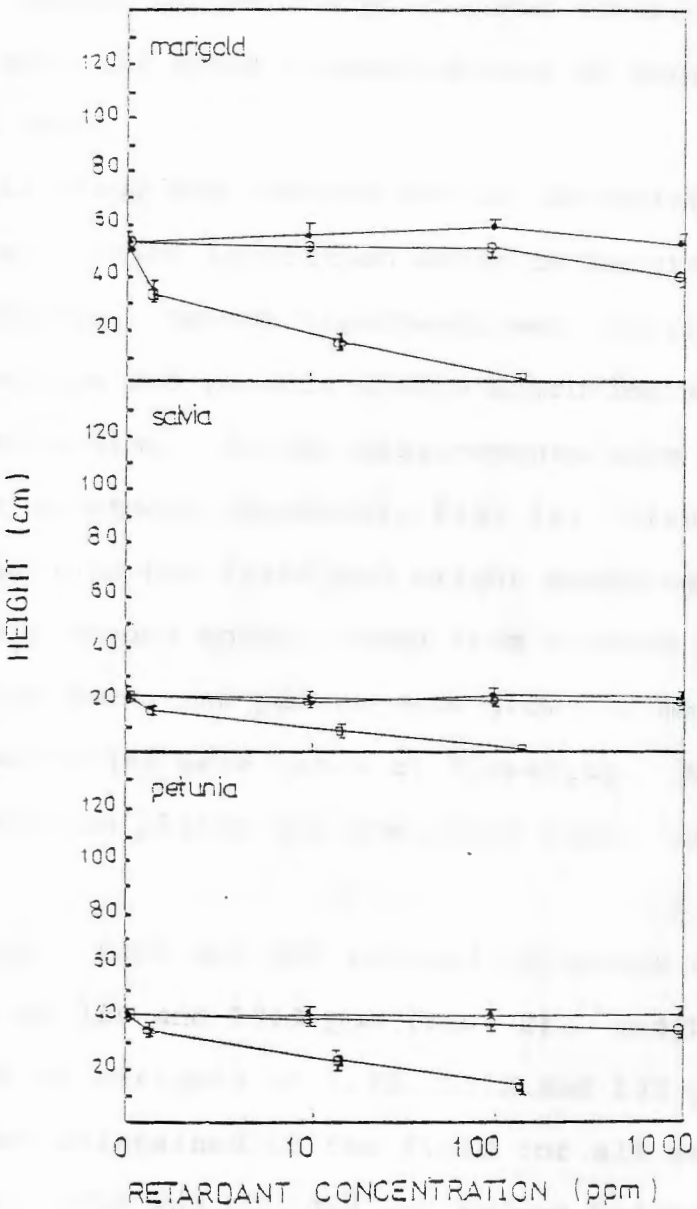


Figure 1. Height of marigold, salvia and petunia plants one month after treatment with SADH (•—•), CCC (o—o) or Ancymidol (□—□).

toxic.

Petunia: SADH did not reduce internode elongation in petunia (Fig. 1). Growth was inhibited by CCC only at 1000 ppm. Height of petunia plants was reduced following treatment with all three concentrations of Ancymidol.

II. Field Study

A field study was carried out to determine whether internode elongation inhibition would be maintained under field conditions. Drench treatments were applied to marigold, salvia and petunia plants approximately two weeks after transplanting. Height measurements were taken one month after treatment (Appendix, Fig. 1). Plants were transplanted into the field and height measurements were taken after a second month. Seed from treated plants was collected and sown, and plants were grown to maturity. Height measurements were taken at flowering. Results on second generation plants are presented under indirect seed treatments.

Marigold: SADH and CCC reduced internode elongation of marigold at 100 and 1000 ppm (Fig. 2). Ancymidol reduced height of marigold at 1.32, 13.2 and 132 ppm. Retardation was maintained in the field for all treatments.

Salvia: SADH and CCC did not reduce height of salvia, and treatment with 100 ppm SADH and CCC stimulated growth (Fig. 2). Internode elongation was temporarily inhibited in plants treated with 1.32 ppm Ancymidol but the inhibitory effect was outgrown after a month in the field.

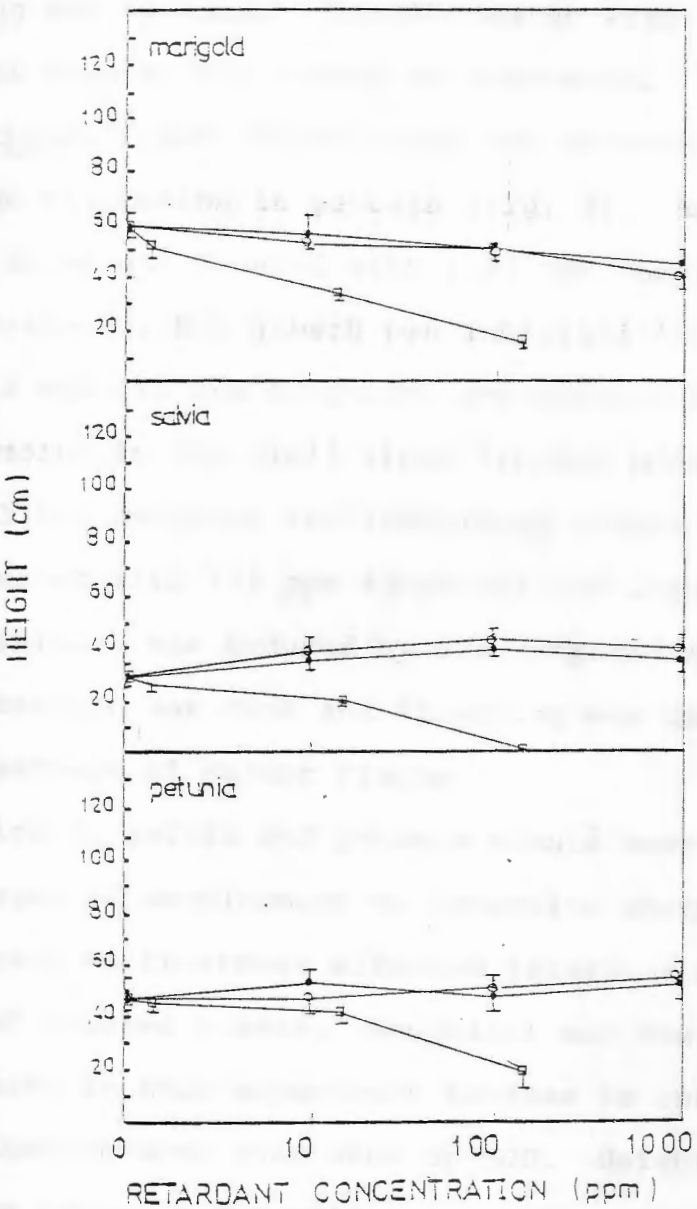


Figure 2. Height of marigold, salvia and petunia plants treated with SADH (●—●), CCC (○—○), or Ancymidol (□—□) after one month in the field.

Treatment with 13.2 ppm Ancymidol reduced internode elongation, but plants were severely stunted and never grew taller than 18 cms. Coloration was black/green and flowering was delayed. Plants treated with 132 ppm Ancymidol died within a week of treatment.

Petunia: SADH and CCC were not effective in reducing internode elongation in petunia (Fig. 2). Height was not reduced in plants treated with 1.32 ppm Ancymidol one month after treatment, but growth was inhibited in plants treated with 13.2 and 132 ppm Ancymidol one month after treatment. After a month in the field those treated with 13.2 ppm Ancymidol had outgrown the inhibitory effect and 60% of those treated with 132 ppm Ancymidol had died. Height of those remaining was reduced by 60% compared to controls. Leaf coloration was dark and flowering was delayed

III. Treatment of Parent Plants

Marigold, salvia and petunia plants were treated at three stages of development to determine whether developmental stage at treatment affected internode elongation in progeny of treated plants. Ancymidol was the only retardant used in this experiment because it inhibited internode elongation more than SADH or CCC. Height measurements were taken at flowering. Seed from treated plants was collected and sown, and plants were grown to maturity. Height measurements were taken at flowering. Results on second generation plants are presented under indirect seed treatments.

Marigold: Treatment with 1.32 and 13.2 ppm Ancymidol retarded growth of stage I marigolds (Fig. 3). The plants which were most attractive, that is, the plants which had the darkest and densest foliage and which were retarded without being stunted, were produced by treatment with 13.2 ppm Ancymidol. Treatment with 132 ppm Ancymidol at stage I was toxic.

Stage II marigolds treated with 1.32 and 13.2 ppm Ancymidol were not significantly shorter than controls. Plants treated with 132 ppm Ancymidol died.

Height was not reduced by treatment of stage III plants with 1.32 or 13.2 ppm Ancymidol, and plants treated with 132 ppm Ancymidol at stage III died.

Salvia: Treatment with 1.32 ppm Ancymidol had no effect on height of salvia plants treated at stage I (Fig. 3). The most effective height control of salvia was achieved with plants treated with 13.2 ppm Ancymidol, but these plants were stunted and did not produce seed. Plants treated with 132 ppm Ancymidol at stage I died.

Treatment of stage II plants with 1.32 ppm Ancymidol did not inhibit growth, but effective height control was achieved with stage II plants treated with 13.2 and 132 ppm Ancymidol.

Treatment with 1.32 ppm Ancymidol had no inhibitory effect on stage III salvia plants. However, height of stage III plants treated with 13.2 and 132 ppm Ancymidol was significantly reduced.

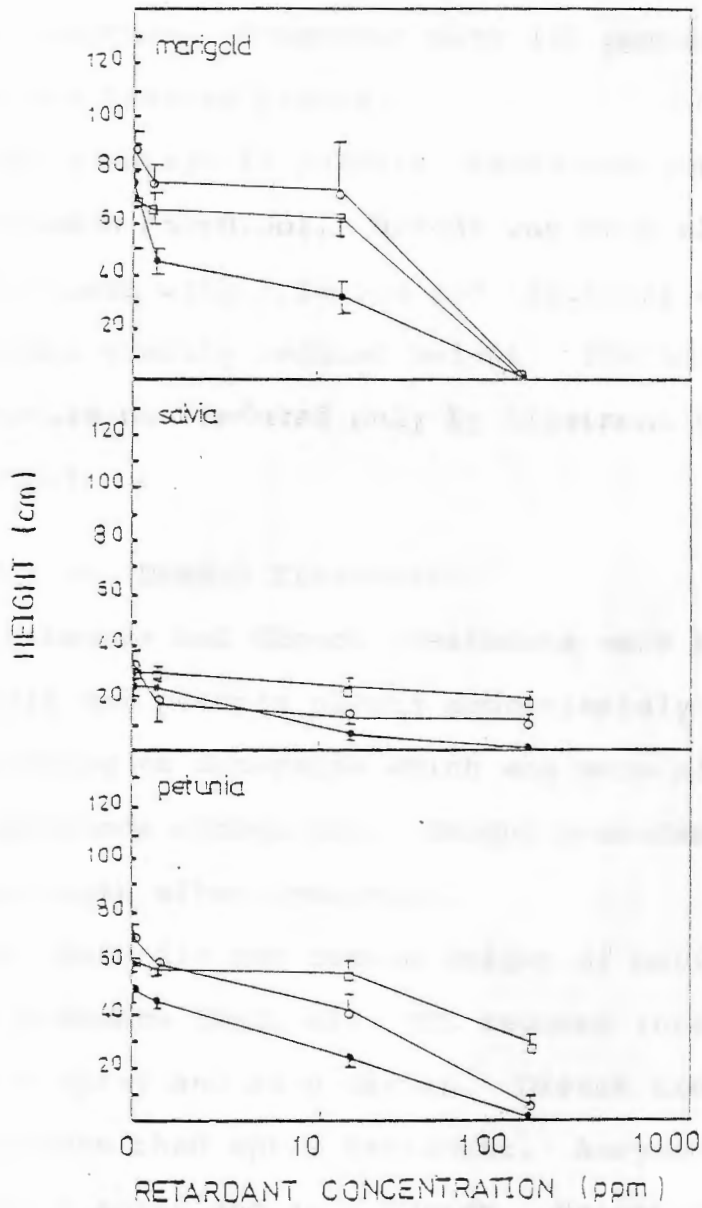


Figure 3. Height at flowering of marigold, salvia, and petunia plants treated with Ancymidol at stages I (•—•), II (o—o), or III (□—□).

Petunia: Treatment with 1.32 ppm Ancymidol had no effect on height of stage I petunias (Fig. 3). Treatment with 13.2 ppm Ancymidol produced the most attractive plants. These plants were compact but not stunted, and were 46% of the height of controls. Treatment with 132 ppm Ancymidol at stage I killed treated plants.

The height of stage II petunia plants was reduced by all treatments with Ancymidol. Height was only slightly reduced by treatment with 1.32 ppm and treatment with 132 ppm Ancymidol greatly reduced height. The height of stage III petunias was reduced only by treatment with 132 ppm Ancymidol.

Spray Treatment vs. Drench Treatment

Spray treatments and drench treatments were applied to marigold, salvia and petunia plants approximately two weeks after transplanting to determine which was more effective in reducing internode elongation. Height measurements were taken one month after treatment.

Marigold: SADH did not reduce height of marigold as a spray or as a drench (Fig. 4). CCC reduced internode elongation as a spray and as a drench. Drench treatment reduced height more than spray treatment. Ancymidol reduced height as a spray and as a drench. Height was reduced more by drench application than by spray application.

Salvia: SADH did not reduce height of salvia when

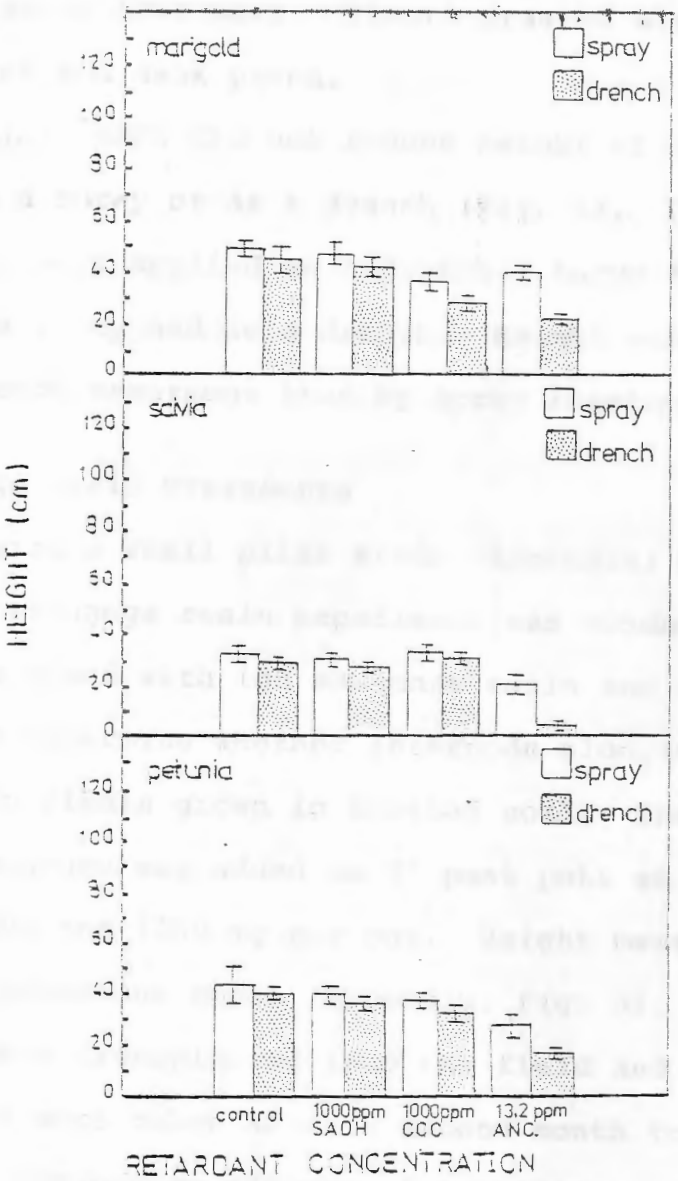


Figure 4. Height of marigold, salvia and petunia plants one month after drench or spray treatment with SADH, CCC or Ancymidol.

applied as a spray or as a drench (Fig. 4). CCC did not reduce height as a spray or as a drench. Ancymidol treatment reduced height of salvia as both a spray and as a drench. Drench treatment with Ancymidol reduced height more than spray treatment. Plants treated with Ancymidol were compact and dark green.

Petunia: SADH did not reduce height of petunia when applied as a spray or as a drench (Fig. 4). CCC reduced height only when applied as a drench. Ancymidol reduced height as a spray and as a drench. Height was reduced more by drench treatment than by spray treatment.

Ion Exchange Resin Treatments

Following a small pilot study (Appendix, Fig. 2), a larger ion exchange resin experiment was conducted. Ancymidol was mixed with ion exchange resin and amended to the soil to determine whether internode elongation would be inhibited in plants grown in treated soil. The Ancymidol and resin mixture was added to 3" peat pots at rates of 0, 100, 250, 500 and 1000 mg per pot. Height measurements were taken after one month (Appendix, Fig. 3). Plants in peat pots were transplanted into the field and height measurements were taken after a second month to determine whether the inhibitory effects of treatment would be maintained under field conditions.

Marigold: The height of marigold plants was not significantly reduced following amendment of 100 mg of

beads to each 3" peat pot (Fig. 5). A height reduction was observed in replicate A only, following the addition of 250 mg of beads to each pot. Addition of 500 mg of beads to each pot inhibited growth in replicate A plants after one and two months, but in replicate B plants the inhibitory effect was present after one month but not after a second month in the field. Addition of 1000 mg of beads to each pot significantly reduced height of marigolds in both replicates two months after treatment.

Salvia: Height of salvia plants was not reduced with 100 mg of beads added to each pot, but was significantly reduced after one month and after a second month in the field with 250 mg, 500 mg, and 1000 mg of beads added to each pot (Fig. 5). Plants grown in pots with 1000 mg of beads amended to the soil were extremely compact and dark green after a month in the field, and remained significantly shorter than controls at flowering.

Petunia: Petunias were less responsive than marigolds or salvia to soil amended with Ancymidol. No inhibitory effect was observed with 100 or 250 mg of beads added to each pot (Fig. 5). Growth of replicate A plants was inhibited after one month following addition of 500 mg of beads to each pot, but the inhibitory effect was outgrown after a month in the field. The inhibitory effect was not outgrown in replicate B plants. Plant growth was inhibited in both replicates at the 1000 mg level which was not outgrown after a month in the field.

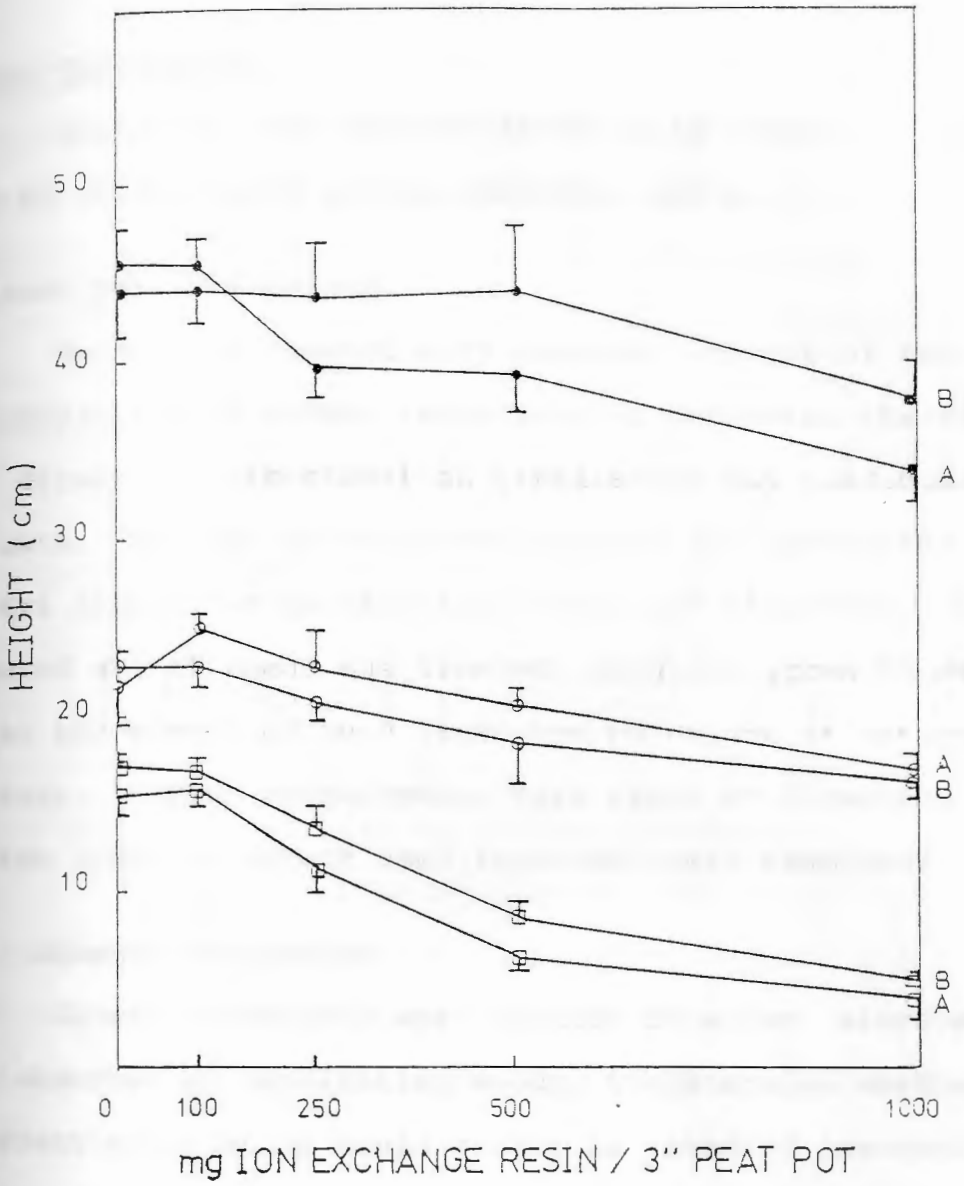


Figure 5. Height at flowering of replicates A and B marigold (●—●), salvia (o—o) and petunia (□—□) plants treated with Ancymidol mixed with ion exchange resin amended to the growing medium.

Seed Treatments

Chemicals were applied directly to seeds, or indirectly by treatment of plants producing seeds.

Direct Seed Treatments

Seeds were treated with aqueous, acetone or talc formulations of growth retardants to determine the effects of direct seed treatment on germination and subsequent growth. One set of seeds was treated and germinated in petri dishes for germination counts and discarded. A second set of seeds was treated, sown and grown to determine the effect of seed treatment on height of mature plants. Height measurements were taken at flowering. Three types of direct seed treatment were examined:

I. Aqueous Treatments

Growth retardants were applied in water, since water is absorbed by germinating seeds, to determine whether retardant application would result in retarded internode elongation in plants grown from treated seed. Seeds were treated for 24 hours at room temperature. Longer treatment resulted in germination, as evidenced by radicle appearance. Seeds were treated for 48 hours at approximately 4°C. All treated seeds were dried for 24 hours. Percent germination and rate of germination were noted. Rate of germination was evaluated by noting the day on which the greatest number of seeds germinated following treatment.

Marigold, Room Temperature: Treatment with SADH at

room temperature did not alter percent germination (Appendix, Fig. 4) or rate of germination (Appendix, Table 1) of marigold seeds, and room temperature treatments with aqueous SADH did not retard subsequent plant growth (Fig. 6). Treatment with 100 and 1000 ppm SADH stimulated growth, but only following treatment in winter.

Treatment with CCC at room temperature did not affect percent germination (Appendix, Fig. 4) or rate of germination (Appendix, Table 1) of marigold seeds. CCC treatment caused a stimulation of growth in plants grown from treated seeds (Fig. 6). The growth stimulation followed treatment with 10, 100 and 1000 ppm CCC in winter. Treatment in summer did not stimulate growth.

Treatment with Amo-1618 did not affect percent germination (Appendix, Fig. 4) or rate of germination (Appendix, Table 1). Growth of plants treated with 1000 ppm Amo-1618 was stimulated, but the stimulatory effect was lost at flowering (Fig. 7).

Percent germination of marigold seeds was not affected by treatment with 1.32 or 13.2 ppm Ancymidol at room temperature (Appendix, Fig. 4). Treatment with 132 ppm Ancymidol reduced percent germination by 26% and delayed germination (Appendix, Table 1). Growth of marigold plants was stimulated following seed treatment with 1.32 and 13.2 ppm Ancymidol in winter (Fig. 6). Height was reduced by treatment with 132 ppm Ancymidol in winter and all treatments reduced internode elongation in summer.

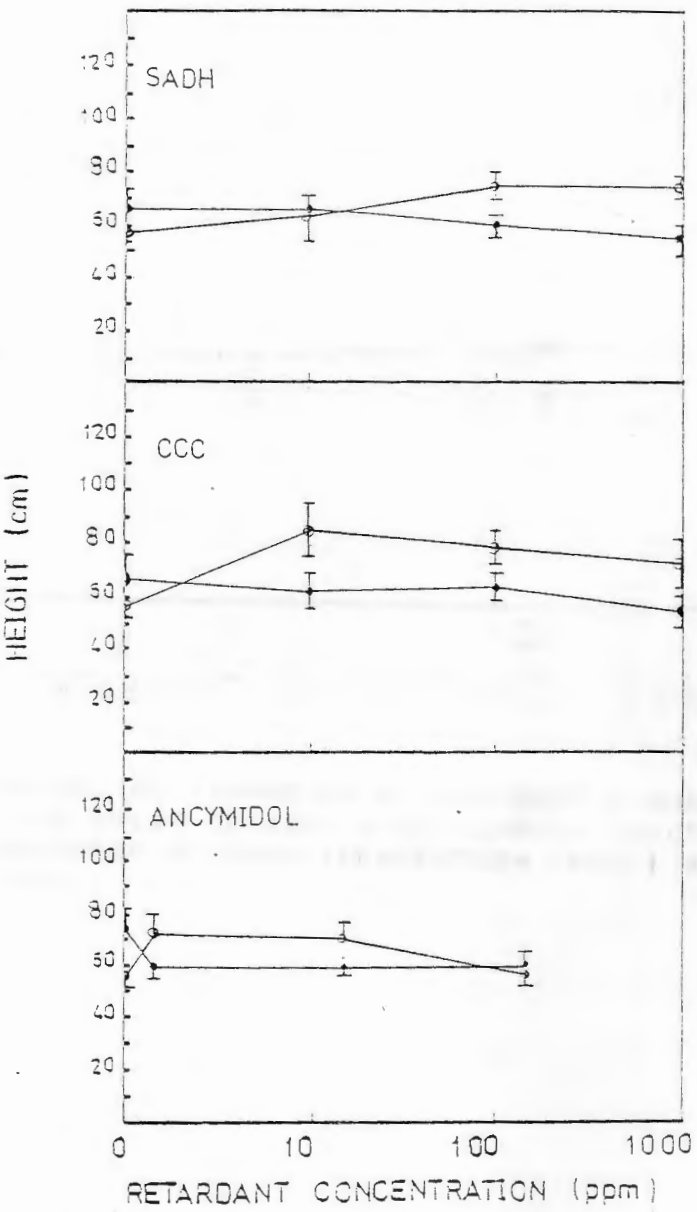


Figure 6. Height at flowering of marigold plants grown from seeds treated with aqueous solutions of SADH, CCC or Ancymidol at room temperature in winter (o—o) and in summer (•—•).

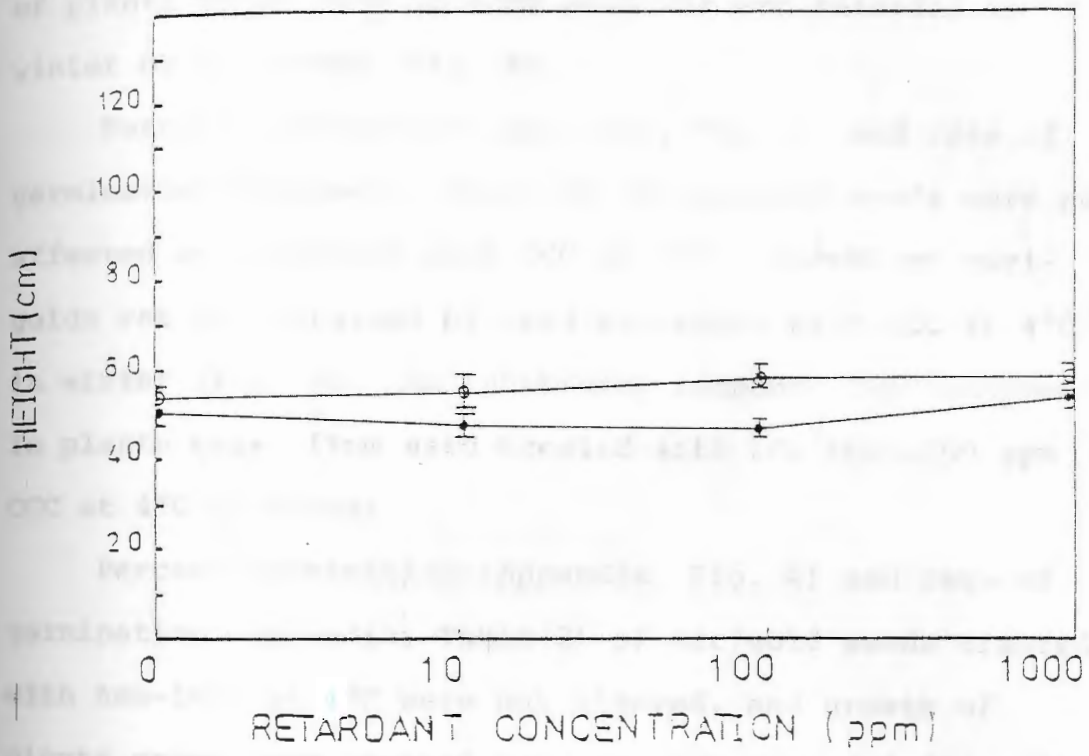


Figure 7. Height at flowering or marigold plants grown from seeds treated with aqueous solutions of Amo-1618 at room temperature (•—•) and 4°C (o—o).

Marigold, 4°C: Treatments with SADH at 4°C did not affect percent germination (Appendix, Fig. 4) or rate of germination (Appendix, Table 2) of marigold seeds. Growth of plants grown from treated seed was not retarded in winter or in summer (Fig. 8).

Percent germination (Appendix, Fig. 4) and rate of germination (Appendix, Table 2) of marigold seeds were not affected by treatment with CCC at 4°C. Growth of marigolds was not retarded by seed treatment with CCC at 4°C in winter (Fig. 8). An inhibitory response was observed in plants grown from seed treated with 100 and 1000 ppm CCC at 4°C in summer

Percent germination (Appendix, Fig. 4) and rate of germination (Appendix, Table 2) of marigold seeds treated with Amo-1618 at 4°C were not altered, and growth of plants grown from treated seed was not retarded (Fig. 7).

Percent germination was not affected by treatment with Ancymidol at 4°C (Appendix, Fig. 4). Germination was delayed by one day following treatment with 132 ppm Ancymidol (Appendix, Table 2). Growth was retarded in plants grown from seed treated with 1.32, 13.2 and 132 ppm Ancymidol at 4°C in summer (Fig. 8). Only treatment with 132ppm Ancymidol at 4°C reduced plant height in winter.

Salvia, Room Temperature: Treatment with 10 ppm SADH at room temperature reduced germination by 27% (Appendix, Fig. 5). Treatment with 100 ppm SADH increased germination by 20%. Treatment with 1000 ppm SADH reduced

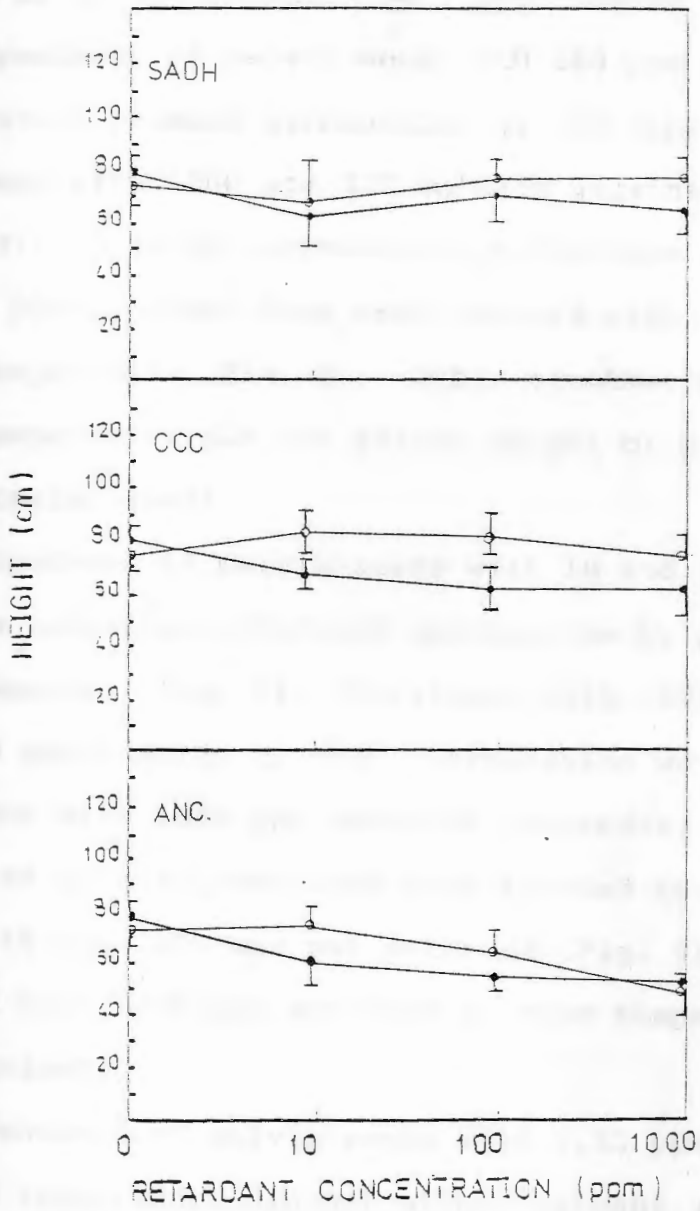


Figure 8. Height at flowering of marigold plants grown from seeds treated with aqueous solutions of SADH, CCC or Ancymidol at 4°C in winter (o—o) and in summer (•—•).

germination by 67%. Rate of germination was not changed by treatment with SADH at room temperature (Appendix, Table 3). No SADH treatment at room temperature retarded growth of salvia plants grown from treated seed (Fig. 9).

Treatment of salvia seed with 100 ppm CCC at room temperature reduced germination by 27% (Appendix, Fig. 5). Treatment with 1000 ppm CCC delayed germination (Appendix, Table 3). A slight stimulatory effect was observed in salvia plants grown from seed treated with 100 ppm CCC at room temperature (Fig. 9). Other treatments with CCC at room temperature did not affect height of plants grown from treated seeds.

Treatment of salvia seeds with 10 and 100 ppm Amo-1618 at room temperature reduced germination by approximately 33% (Appendix, Fig. 5). Treatment with 1000 ppm Amo-1618 reduced germination by 93%. Germination was delayed by treatment with 1000 ppm Amo-1618 (Appendix, Table 3). Growth of plants grown from seed treated at room temperature with Amo-1618 was not retarded (Fig. 9). Seeds treated with 1000 ppm Amo-1618 at room temperature did not germinate.

Treatment of salvia seeds with 1.32 ppm Ancymidol at room temperature did not affect percent germination, but higher concentrations of Ancymidol suppressed germination (Appendix, Fig. 5). Rate of germination of salvia was not affected by treatment with Ancymidol at room temperature (Appendix, Table 3). Growth of salvia plants

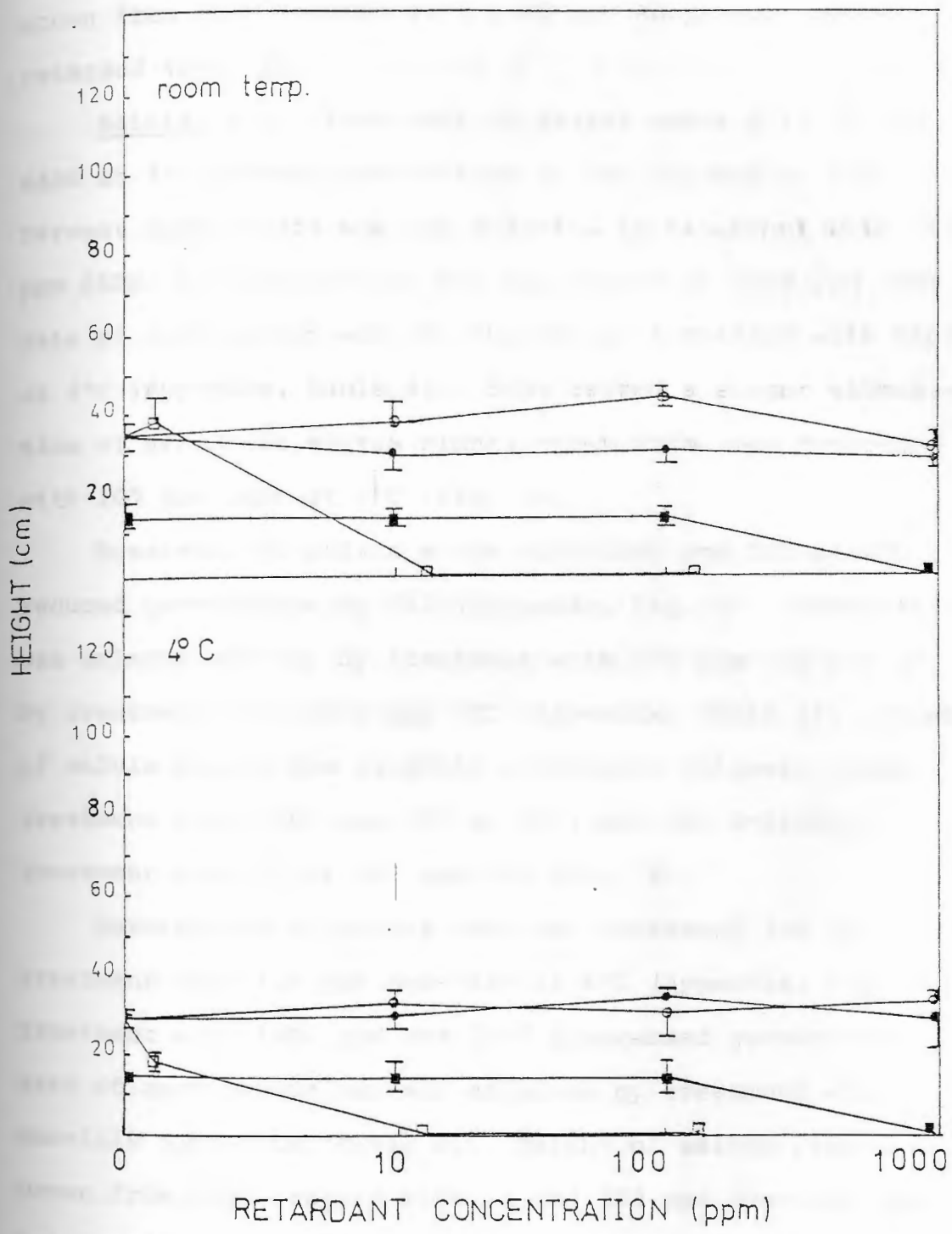


Figure 9. Height at flowering of salvia plants grown from seeds treated with aqueous solutions of SADH (●—●), CCC (○—○), Amo-1618 (■—■), or Ancymidol (□—□) at room temperature and 4°C.

grown from seed treated with 1.32 ppm Ancymidol was not retarded (Fig. 9).

Salvia, 4°C: Treatment of salvia seeds with 10 ppm SADH at 4°C reduced germination by 38% (Appendix, Fig. 5). Percent germination was not affected by treatment with 100 ppm SADH, but germination was suppressed by 1000 ppm SADH. Rate of germination was not changed by treatment with SADH at 4°C (Appendix, Table 4). SADH caused a slight stimulation of growth in salvia plants grown from seed treated with 100 ppm SADH at 4°C (Fig. 9).

Treatment of salvia seeds with 1000 ppm CCC at 4°C reduced germination by 31% (Appendix, Fig. 5). Germination was delayed one day by treatment with 100 ppm CCC but not by treatment with 1000 ppm CCC (Appendix, Table 4). Growth of salvia plants was slightly stimulated following seed treatment with 1000 ppm CCC at 4°C, but not following treatment with 10 or 100 ppm CCC (Fig. 9).

Germination of salvia seed was increased 30% by treatment with 100 ppm Amo-1618 at 4°C (Appendix, Fig. 5). Treatment with 1000 ppm Amo-1618 suppressed germination. Rate of germination was not affected by treatment with Amo-1618 (Appendix, Table 4). Height of salvia plants grown from seed treated with 10 and 100 ppm Amo-1618 was not significantly different from controls (Fig. 9).

Treatment of salvia seeds with 1.32 ppm Ancymidol did not alter percent germination, and treatment with 13.2 and 132 ppm Ancymidol suppressed germination (Appendix, Fig. 5).

Rate of germination was not affected by treatment with 1.32 ppm Ancymidol (Appendix, Table 4). Growth of salvia plants was inhibited following seed treatment with 1.32 ppm Ancymidol at 4°C (Fig. 9).

Petunia, Room Temperature: Treatment of petunia with 100 ppm SADH decreased germination by 22% (Appendix, Fig. 6). Rate of germination was not altered by SADH treatment (Appendix, Table 5). Treatment with SADH at room temperature had no effect on height of plants grown from treated seeds (Fig. 10).

Treatment with 10 ppm CCC at room temperature reduced germination of petunia by 11% (Appendix, Fig. 6). Other treatments with CCC at room temperature did not significantly alter germination. Rate of germination was not affected by treatment with CCC (Appendix, Table 5). No inhibitory effect was observed in petunia plants grown from seed treated with CCC at room temperature (Fig. 10).

Treatment of petunia seeds with 1000 ppm Amo-1618 at room temperature suppressed germination (Appendix, Fig. 6). Other treatments did not alter germination. Rate of germination was not altered by any treatments with Amo-1618 at room temperature (Appendix, Table 5). Height of petunia plants was not changed by seed treatment with Amo-1618 at room temperature (Fig. 10).

Germination of petunia seeds was reduced by 22% by treatment with 1.32 ppm Ancymidol, 67% by treatment with 13.2 ppm Ancymidol, and germination was completely sup-

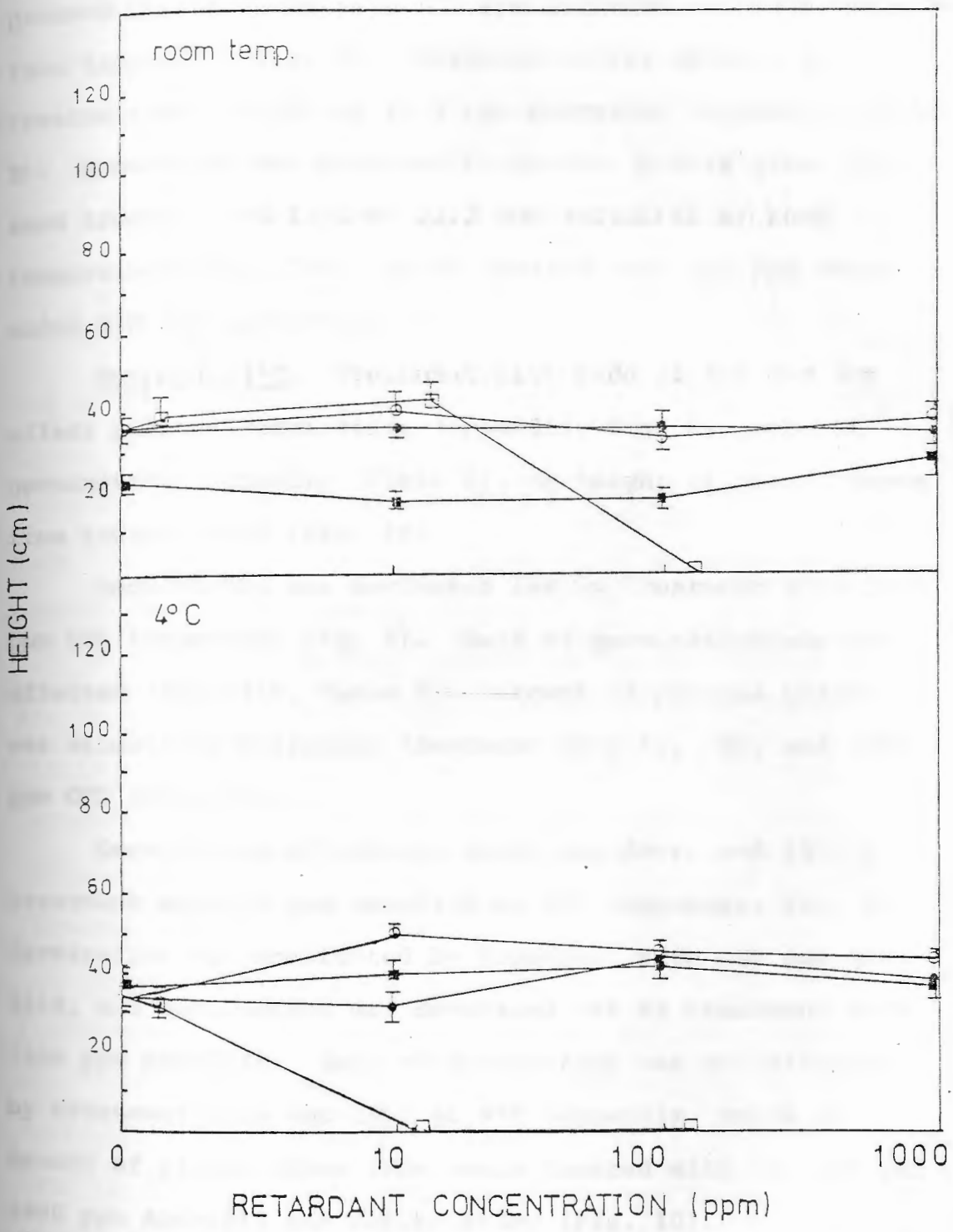


Figure 10. Height at flowering of petunia plants grown from seeds treated with aqueous solutions of SADH (●—●), CCC (○—○), Amo-1618 (■—■) or Ancymidol (□—□) at room temperature and 4°C.

pressed by treatment with 132 ppm Ancymidol at room temperature (Appendix, Fig. 5). Germination was delayed by treatment with 1.32 and 13.2 ppm Ancymidol (Appendix, Table 5). Growth was not retarded in petunia plants grown from seed treated with 1.32 or 13.2 ppm Ancymidol at room temperature (Fig. 10). Seeds treated with 132 ppm Ancymidol did not germinate.

Petunia, 4°C: Treatment with SADH at 4°C did not affect percent germination (Appendix, Fig. 6), rate of germination (Appendix, Table 6), or height of plants grown from treated seed (Fig. 10).

Germination was decreased 18% by treatment with 1000 ppm CCC (Appendix, Fig. 6). Rate of germination was not affected (Appendix, Table 6). Growth of petunia plants was stimulated following treatment with 10, 100, and 1000 ppm CCC (Fig. 10).

Germination of petunia seeds was decreased 44% by treatment with 10 ppm Amo-1618 at 4°C (Appendix, Fig. 6). Germination was unaffected by treatment with 100 ppm Amo-1618, and germination was decreased 94% by treatment with 1000 ppm Amo-1618. Rate of germination was not affected by treatment with Amo-1618 at 4°C (Appendix, Table 6). Growth of plants grown from seeds treated with 10, 100 and 1000 ppm Amo-1618 was not retarded (Fig. 10).

Germination was reduced 53% by treatment with 13.2 ppm Ancymidol at 4°C (Appendix, Fig 6). Seeds failed to germinate following treatment with 132 ppm Ancymidol. Germina-

tion was delayed one day following treatment with 1.32 and 13.2 ppm Ancymidol at 4°C (Appendix, Table 6). Growth of plants grown from seeds treated with 1.32 ppm Ancymidol was not inhibited (Fig. 10). Seeds failed to germinate following treatment with 13.2 and 132 ppm Ancymidol at 4°C.

II. Acetone Treatments

Since the insecticide DDT was absorbed by wheat seeds and recovered from wheat seedlings when applied to seeds in acetone (54), marigold, salvia and petunia seeds were treated with acetone formulations of retardants to determine whether internode elongation would be retarded in plants grown from treated seeds.

Marigold and petunia seeds were treated for 24 hours. Salvia seeds were treated for one hour, since longer treatments prevented germination. Counts of lateral branches were taken on plants grown from seeds treated with acetone solutions of growth retardants, because acetone treatment seemed to promote branching.

Marigold: Germination was increased by 18% following treatment with 10 and 100 ppm SADH in acetone (Appendix, Fig. 7). Rate of germination was not affected by treatment with SADH in acetone (Appendix, Table 7). Seed treatment had no inhibitory effect on plants grown from treated seeds (Fig. 11).

Treatment with CCC in acetone had no effect on percent germination (Appendix, Fig. 7) or rate of germination

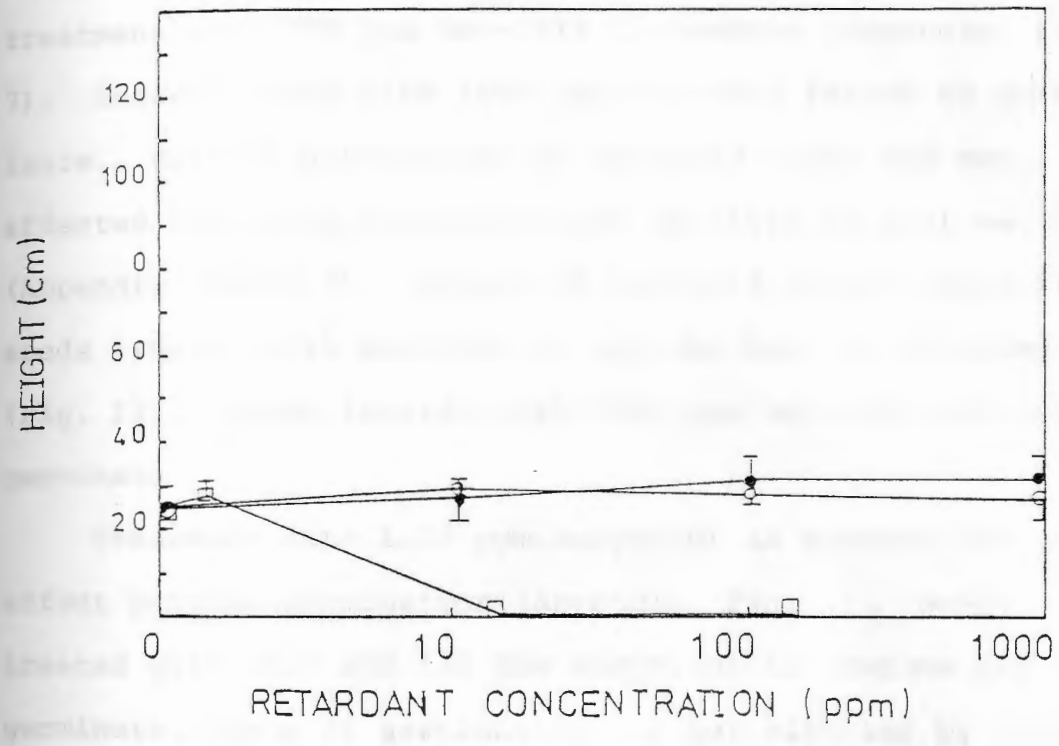


Figure 11. Height at flowering of marigold plants grown from seeds treated with acetone solutions of SADH (•—•), CCC (o—o) and Ancymidol (□—□).

(Appendix, Table 7) of marigold seeds. Growth of plants grown from treated seeds was not altered (Fig. 11).

Germination of marigold seeds was increased 31% by treatment with 10 ppm Amo-1618 in acetone, and 23% by treatment with 100 ppm Amo-1618 in acetone (Appendix, Fig. 7). Seeds treated with 1000 ppm Amo-1618 failed to germinate. Rate of germination of marigold seeds was not affected following treatment with Amo-1618 in acetone (Appendix, Table 7). Growth of marigold plants grown from seeds treated with Amo-1618 in acetone was not retarded (Fig. 12). Seeds treated with 1000 ppm Amo-1618 did not germinate.

Treatment with 1.32 ppm Ancymidol in acetone did not affect percent germination (Appendix, Fig. 7). Seeds treated with 13.2 and 132 ppm Ancymidol in acetone did not germinate. Rate of germination was not affected by treatment with 1.32 ppm Ancymidol in acetone (Appendix, Table 7). Height was not reduced in marigold plants grown from treated seed (Fig. 11).

Acetone treatment of marigold seeds promoted secondary and in some cases primary branching in plants grown from treated seeds (Table 1). Primary branching was increased only in plants grown from seed treated with 100 and 1000 ppm SADH in acetone. Secondary branching was increased in plants grown from seed treated with CCC in acetone. All marigold plants grown from seeds treated with acetone solutions had more secondary laterals than distilled water

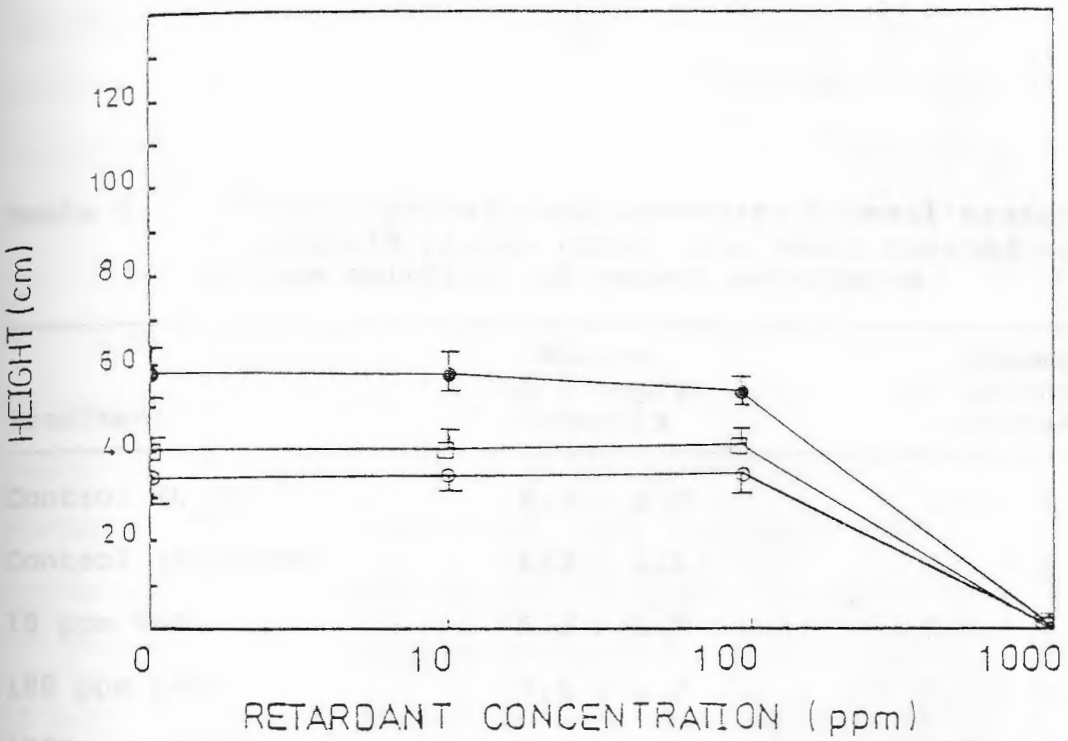


Figure 12. Height at flowering of marigold (•—•), salvia (o—o) and petunia (□—□) plants grown from seeds treated with acetone solutions of Amo-1618.

Table 1. Number of primary and secondary lateral branches of marigold plants grown from seeds treated with acetone solutions of growth retardants.

Treatment	Number of Primary Laterals	Number of Secondary Laterals
Control (H_2O)	4.3 ± 1.0	1.0 ± 1.2
Control (Acetone)	4.3 ± 1.5	3.9 ± 1.2
10 ppm SADH	5.2 ± 1.9	5.4 ± 1.3
100 ppm SADH	7.6 ± 1.2	5.7 ± 1.9
1000 ppm SADH	7.2 ± 1.4	6.0 ± 1.5
10 ppm CCC	6.4 ± 1.2	8.2 ± 1.3
100 ppm CCC	5.8 ± 1.6	8.0 ± 1.0
1000 ppm CCC	5.2 ± 1.8	7.3 ± 1.5
1.32 ppm Ancymidol	5.0 ± 1.8	4.6 ± 2.4
13.2 ppm Ancymidol	-	-
132 ppm Ancymidol	-	-

controls.

Salvia: Germination was reduced 27% by treatment with 10 ppm SADH in acetone, 20% by treatment with 100 ppm SADH and 40% by treatment with 1000 ppm SADH (Appendix, Fig. 7). Rate of germination was not affected by treatment with SADH in acetone (Appendix, Table 8). Most seeds sown for evaluation of mature plants failed to germinate.

Germination was reduced 33% by treatment with 10 ppm CCC in acetone, 40% by treatment with 100 ppm CCC, and 73% by treatment with 1000 ppm CCC (Appendix, Fig. 7). Rate of germination was not affected by treatment with CCC in acetone (Appendix, Table 8). Very few seeds sown for evaluation of mature plants germinated.

Treatment of salvia seed with 10 and 100 ppm Amo-1618 in acetone did not affect percent germination (Appendix, Fig. 7). Germination was reduced by 90% following treatment with 1000 ppm Amo-1618. Rate of germination of salvia seeds was not affected by treatment with Amo-1618 in acetone (Appendix, Table 7). Height of salvia plants grown from seeds treated with acetone solutions of Amo-1618 was not significantly different from controls (Fig. 12). Seeds treated with 1000 ppm Amo-1618 failed to germinate.

Germination of salvia seeds was reduced 68% by treatment with 1.32 ppm Ancymidol in acetone (Appendix, Fig. 7). Other treatments with Ancymidol in acetone suppressed germination. Treatment with 1.32 ppm Ancymidol did not alter rate of germination (Appendix, Table 8). Growth of

salvia plants grown from seed treated with 1.32 ppm Ancymidol in acetone was not retarded.

Very few salvia seeds germinated following treatment with growth retardants in acetone. Data on lateral branching was not taken, but plants grown from treated seeds were compact and bushy with many lateral branches.

Petunia: Germination of petunia was increased 25% by treatment with 10 ppm SADH in acetone, and 19% by treatment with 100 ppm SADH (Appendix, Fig. 7). Germination of petunia seeds treated with 1000 ppm SADH in acetone was not significantly different from controls. Rate of germination was not affected by treatment with SADH (Appendix, Table 9). Height of petunia plants grown from seed treated with SADH in acetone was not reduced (Fig. 13).

Germination of petunia seeds was reduced 19% by treatment with 100 ppm CCC in acetone and 37% by treatment with 1000 ppm CCC (Appendix, Fig. 7). Germination was delayed one day by treatment with 1000 ppm CCC in acetone (Appendix, Table 9). Height of plants grown from treated seed was not significantly different from controls (Fig. 13).

Percent germination (Appendix, Fig. 7) and rate of germination (Appendix, Table 9) of petunia seeds were not altered by treatment with 10 and 100 ppm Amo-1618 in acetone. Seeds treated with 1000 ppm Amo-1618 failed to germinate. Height of petunia plants grown from seed treated with Amo-1618 in acetone was not retarded (Fig. 12). Seeds treated with 1000 ppm Amo-1618 did not germinate.

TREATMENT 0 - Control (H_2O)

TREATMENT 1 - Control (Acetone)

TREATMENT 2 - 10 ppm SADH

TREATMENT 3 - 100 ppm SADH

TREATMENT 4 - 1000 ppm SADH

TREATMENT 5 - 10 ppm CCC

TREATMENT 6 - 100 ppm CCC

TREATMENT 7 - 1000 ppm CCC

TREATMENT 8 - 1.32 ppm Ancymidol

TREATMENT 9 - 13.2 ppm Ancymidol

TREATMENT 10 - 132 ppm Ancymidol

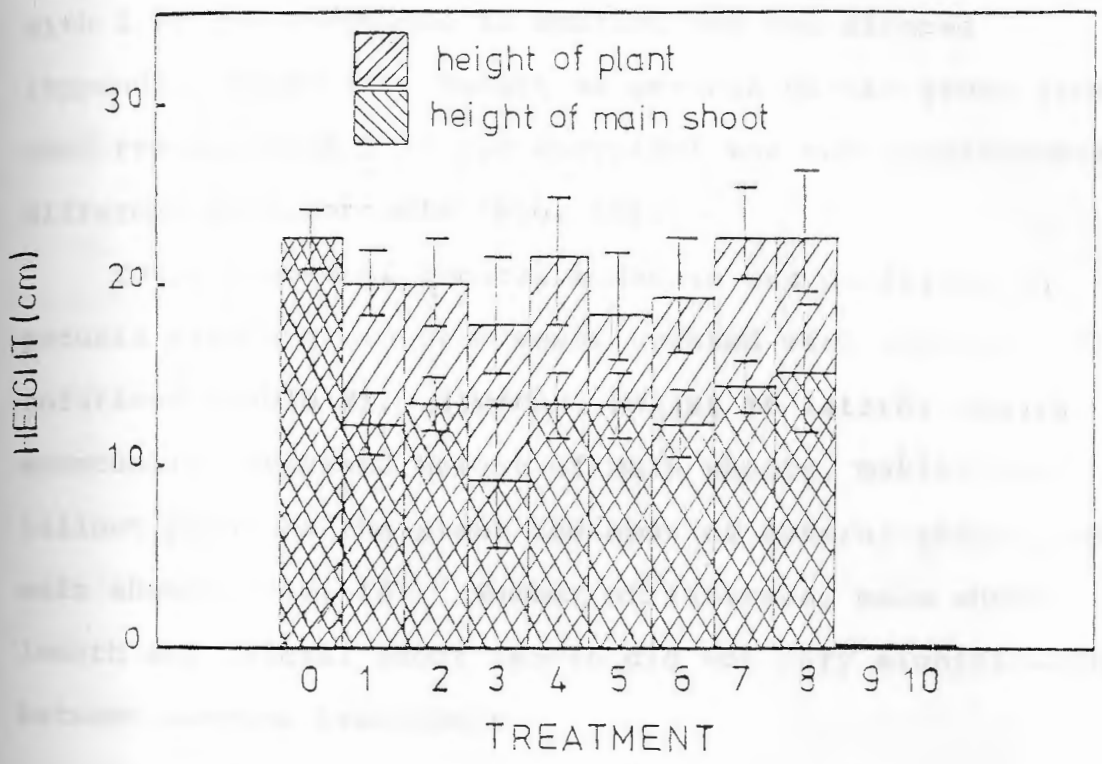


Figure 13. Plant height and main shoot height of petunia plants grown from seeds treated with acetone solutions of growth retardants.

Treatment of petunia seeds with 1.32 ppm Ancymidol in acetone did not affect percent germination (Appendix, Fig. 7). Seeds treated with 13.2 or 132 ppm Ancymidol failed to germinate. Rate of germination of seeds treated with 1.32 ppm Ancymidol in acetone was not altered (Appendix, Table 9). Height of petunia plants grown from seed treated with 1.32 ppm Ancymidol was not significantly different from controls (Fig. 13).

Total number of lateral branches was decreased in petunia plants grown from seeds treated with acetone solutions (Table 2). However, height of lateral shoots eventually surpassed height of main shoots, making the tallest point on the plant the apex of lateral shoots, not main shoots (Fig. 13). Number of laterals, main shoot length and lateral shoot length did not vary significantly between acetone treatments.

III. Talc Treatments

Marigold, salvia and petunia seeds were treated with talc formulations of SADH, CCC and Ancymidol to determine whether internode elongation would be inhibited in bedding plants grown from treated seed. Talc formulations of Ancymidol reduced height of corn plants grown from treated seed (42).

Talc formulations were made by mixing acetone formulations of retardants with talc and air drying the mixtures to powders. Since very little talc actually coated seeds

Table 2. Number of lateral branches of petunia plants grown from seeds treated with acetone solutions of growth retardants.

Treatment	Number of Laterals
Control (H_2O)	7.3 ± 0.5
Control (Acetone)	4.8 ± 0.5
10 ppm SADH	4.6 ± 0.6
100 ppm SADH	5.3 ± 0.4
1000 ppm SADH	5.7 ± 0.6
10 ppm CCC	4.6 ± 0.9
100 ppm CCC	5.2 ± 0.7
1000 ppm CCC	5.0 ± 0.9
1.32 ppm Ancymidol	4.4 ± 0.4
13.2 ppm Ancymidol	-
132 ppm Ancymidol	-

and the retardant was diluted by acetone and then by talc, a highly concentrated solution of Ancymidol was used. Ancymidol was more effective than SADH, CCC or Amo-1618 in retarding growth, so concentrated solutions of the latter three chemicals were not used.

Marigold: Germination of marigold seeds treated with 100 ppm SADH in talc was increased 25% (Appendix, Fig. 8). Treatment with 1000 ppm SADH increased germination 19%. Germination was delayed one day by treatment wiht 1000 ppm SADH in talc (Appendix, Table 10). Height of marigold plants grown from seed treated with talc formulations of SADH was not altered (Fig. 14).

Treatment of marigold seeds with 10 ppm CCC in talc increased germination by 25% (Appendix, Fig. 8). Treatment with 100 ppm CCC did not alter percent germination and treatment with 1000 ppm CCC reduced germination by 19%. Rate of germination of marigold seeds was not affected by treatment with talc formulations of CCC (Appendix, Table 10). Height of marigold plants grown from seed treated with talc formulation of CCC was not altered (Fig. 14).

Percent germination (Appendix, Fig. 8), rate of germination (Appendix, Table 10), and height of marigold plants grown from treated seed (Fig. 14) were not altered by seed treatment with talc formulations of Amo-1618.

Germination of marigold seeds was increased 19% by treatment with 132 and 264 ppm Ancymidol in talc (Appendix,

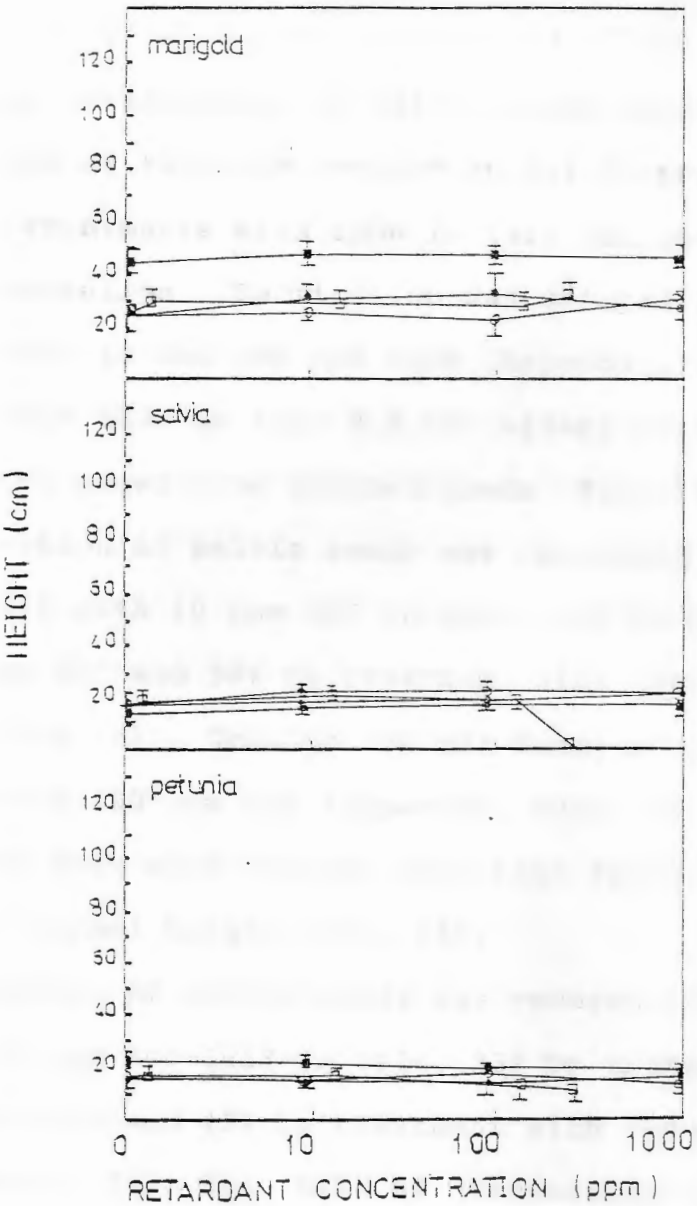


Figure 14. Height at flowering of marigold, salvia and petunia plants grown from seeds treated with talc formulations of SADH (●—●), CCC (○—○), Amo-1618 (■—■) or Ancymidol (□—□).

Fig. 8). Rate of germination of marigold seeds was not affected by treatment with talc formulations of Ancymidol (Appendix, Table 10). Plants grown from seed treated with talc formulations of Ancymidol were of normal height (Fig. 14).

Salvia: Germination of salvia seeds treated with 1000 ppm SADH in talc was reduced by 31% (Appendix, Fig. 8). Other treatments with SADH in talc did not alter percent germination. Germination was delayed one day by treatment with 10 and 100 ppm SADH (Appendix, Table 11). Treatment with SADH in talc did not affect height of salvia plants grown from treated seeds (Fig. 14).

Germination of salvia seeds was decreased 25% following treatment with 10 ppm CCC in talc, 12% by treatment with 100 ppm CCC and 50% by treatment with 1000 ppm CCC (Appendix, Fig. 8). Germination was delayed one day by treatment with 100 ppm CCC (Appendix, Table 11). Salvia plants grown from seed treated with talc formulations of CCC were of normal height (Fig. 14).

Germination of salvia seeds was reduced 27% by treatment with 10 ppm Amo-1618 in talc, 33% by treatment with 100 ppm Amo-1618 and 40% by treatment with 1000 ppm Amo-1618 (Appendix, Fig. 8). Rate of germination (Appendix, Table 11) and height of plants grown from treated seeds (Fig. 14) were not changed by treatment with Amo-1618 in talc.

Germination of salvia seeds was reduced 37% by treatment with 1.32 ppm Ancymidol in talc and 56% by treatment with 13.2 ppm Ancymidol (Appendix, Fig. 8). Seeds treated with talc formulations of 132 and 264 ppm Ancymidol did not germinate. Rate of germination was not affected by treatment (Appendix, Table 11). Plants grown from seeds treated with 1.32, 13.2 and 132 ppm Ancymidol in talc were of normal height (Fig. 14).

Petunia: Treatment with 10, 100 and 1000 ppm SADH in talc increased germination by 11% (Appendix, Fig. 8). Rate of germination was not affected by SADH treatment (Appendix, Table 12) and plants grown from treated seed were of normal height (Fig. 14).

Treatment with talc formulations of CCC did not affect percent germination (Appendix, Fig. 8) rate of germination (Appendix, Table 12) or height of plants grown from treated seed (Fig. 14).

Percent germination (Appendix, Fig. 8) and rate of germination (Appendix, Table 12) were not altered by seed treatment with talc formulations of Amo-1618. A transitory inhibition was observed in petunia plants grown from seed treated with 1000 ppm Amo-1618 but the inhibitory effect was not evident at flowering (Fig. 14).

Percent germiantion of petunia was not affected by treatment with talc formulations of Ancymidol (Appendix, Fig. 8). Germination was delayed one day by treatment with 264 ppm Ancymidol (Appendix, Table 12). Petunia plants

grown from seed treated with talc formulations of Ancymidol were of normal height (Fig. 14).

Indirect Seed Treatments

Seeds were treated indirectly by applying drench treatments to plants producing seed. Seeds were collected, sown and grown to maturity to determine whether internode elongation would be inhibited in second generation plants. Two indirect seed treatment experiments were carried out:

I. Seed Collected From Field Grown Plants

Seeds were collected from field grown plants which had been treated with soil drenches of growth retardants. Seeds were germinated and plants were grown to maturity. Height measurements were taken at flowering.

Marigold: No inhibitory effects were present at flowering in progeny of plants treated with SADH (Fig. 15).

Growth of second generation marigolds was inhibited by CCC only when parent plants were treated with 1000 ppm CCC (Fig. 15).

Progeny of marigolds treated with 1.32 ppm Ancymidol were not significantly shorter than controls but progeny of plants treated with 13.2 ppm Ancymidol were significantly shorter (Fig. 15). Plants treated with 132 ppm Ancymidol did not survive to produce seed.

Salvia: SADH did not retard growth of second generation salvia plants (Fig. 15).

CCC, which stimulated growth of parent plants, did not

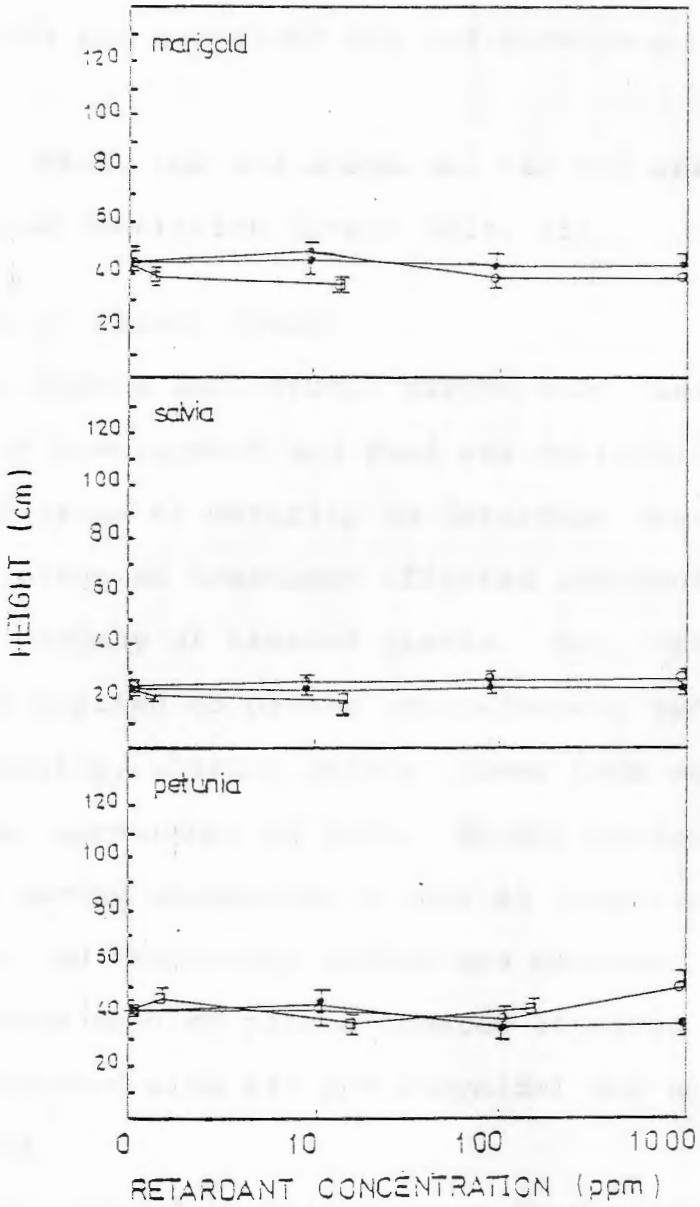


Figure 15. Height at flowering of marigold, salvia and petunia plants grown from seeds collected from field-grown plants treated with SADH (●—●), CCC (○—○) or Ancymidol (□—□).

retard growth of second generation plants (Fig. 15).

Growth of progeny of salvia plants treated with 1.32 and 13.2 ppm Ancymidol was not retarded (Fig. 15). Plants treated with 132 ppm Ancymidol did not survive to produce seed.

Petunia: SADH, CCC and Ancymidol did not retard growth of second generation plants (Fig. 15).

II. Treatment of Parent Plants

Marigold, salvia and petunia plants were treated at three stages of development and seed was collected, germinated and grown to maturity to determine whether developmental stage at treatment affected internode elongation in progeny of treated plants. Soil drenches of Ancymidol were applied to plants approximately two weeks after transplanting, shortly before flower buds were visible, and after appearance of buds. Height measurements were taken on second generation plants at flowering.

Marigold: No inhibitory effect was observed in any plants grown from seed of plants treated at stage I (Fig. 16). Plants treated with 132 ppm Ancymidol did not survive to produce seed.

Height was reduced in palnts grown from seeds taken from plants treated with 1.32 and 13.2 ppm Ancymidol at stage II (Fig. 16). Plants treated with 132 ppm Ancymidol died.

The most effective treatment, 13.2 ppm Ancymidol

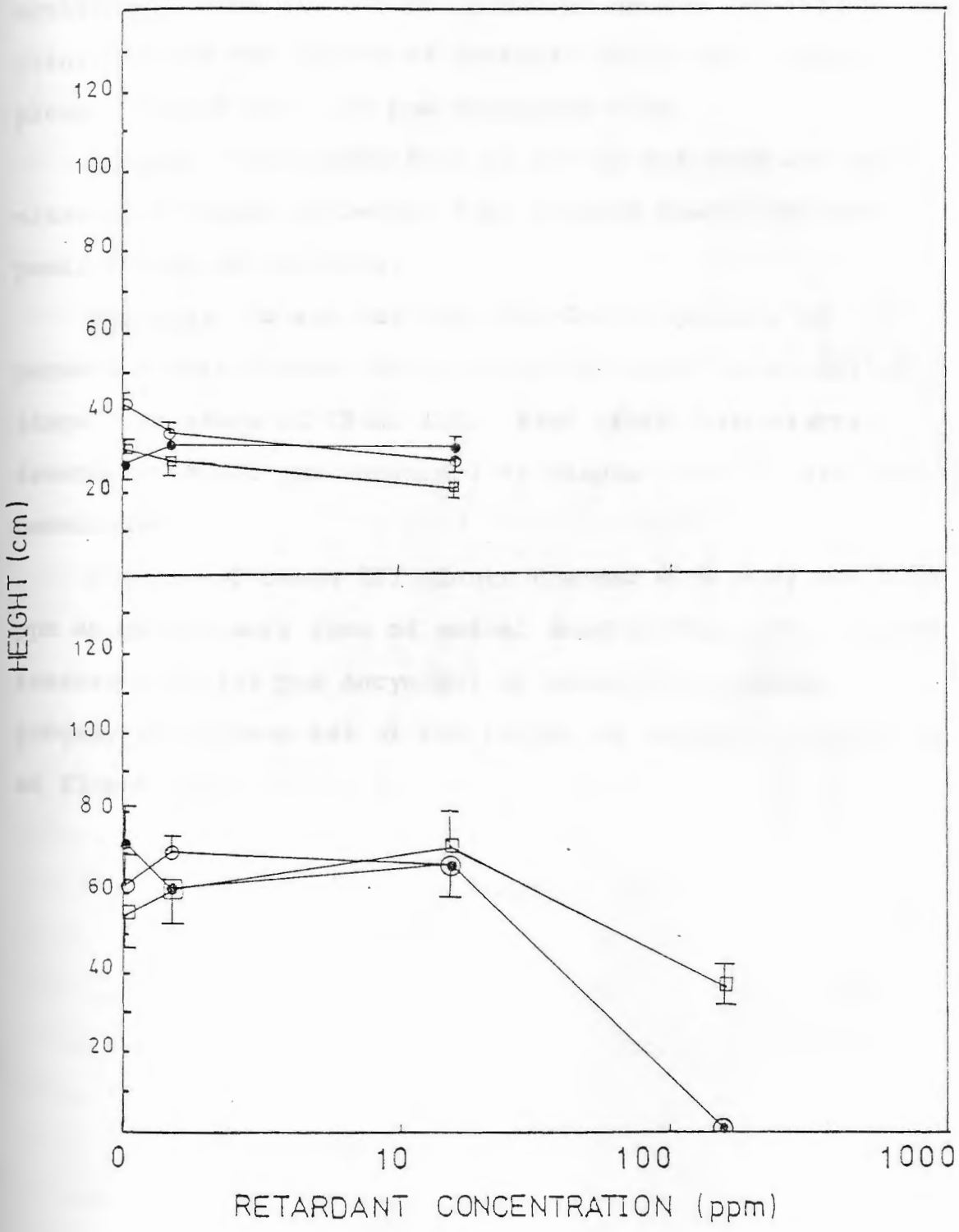


Figure 16. Height at flowering of marigold and petunia plants grown from seeds collected from plants treated at stage I (●—●), II (○—○) or III (□—□).

applied to stage III plants, produced second generation plants 83% of the height of controls (Fig. 16). Parent plants treated with 132 ppm Ancymidol died.

Salvia: Seed production by salvia was poor and germination of seeds collected from treated plants was very poor, except in controls.

Petunia: Growth was not retarded in progeny of petunia plants treated with 1.32 or 13.2 ppm Ancymidol at stage I or stage II (Fig. 16). Seed taken from plants treated with 132 ppm Ancymidol at stages I and II did not germinate.

Progeny of stage III plants treated with 1.32 and 13.2 ppm Ancymidol were also of normal height (Fig. 16). Plants treated with 132 ppm Ancymidol at stage III produced progeny which were 64% of the height of progeny of controls at flowering.

DISCUSSION

Plant Treatments

Stimulation of Growth

In several experiments growth was stimualted by retardant treatment. There are reports of promotive or stimulatory effects of retardants in the literature (2,26, 58,62,80,92). Growth stimulation may follow treatment with low concentrations of retardants. Growth of peas was stimulated following application of 1 ppm CCC (1). In the experiments described in this paper, growth of marigold plants was stimulated following treatment with 100 ppm SADH but not following treatment with 1000 ppm SADH. Growth of salvia was stimulated by 100 ppm SADH and CCC but not by 1000 ppm of these chemicals.

Some inhibitory effects of retardant treatments were outgrown under field conditions. This could be due to a dilution of the chemicals in the soil followed by a stimulation of growth due to the presence of low concentrations of retardants. Growth of Citrus limettoides was reported to be initially retarded but then vigorously stimulated following application of SADH. The stimulation was reportedly due to accumulation of assimilates. Accumulation of photosynthate following retardant treatment may promote growth or flowering (72,80).

Retardants which block GA synthesis cause an accumulation of GA precursors which could be rapidly transformed

into GA following metabolism or inactivation of the retardant. However, it has not been conclusively shown that the primary action of SADH is blockage of GA synthesis (68,87), although it is thought that SADH inhibits synthesis of kauren-19-ol, a GA precursor (71,91).

Inhibitory Action of Ancymidol on Plants

Ancymidol was clearly more effective in retarding growth of annual beding plants than SADH, CCC or Amo-1618. The effectiveness of Ancymidol may be due to its interference in systems not affected by other retardants.

Amo-1618, CCC and Ancymidol block the synthesis of GA (12, 38). In addition, Ancymidol inhibits GA-activated elongation of lettuce seedlings and Benzyladenine (BA) stimulated growth of Xanthium (42). Amo-1618, CCC and SADH do not. Ancymidol therefore counteracts the promotive effects of gibberellin and cytokinin, which other retardants do not. If Ancymidol inhibits growth stimulated by exogenously applied BA and other retardants do not, it may also have an inhibitory effect on processes regulated by endogenous cytokinins, which other retardants may not.

Another factor which may have enhanced the effectiveness of Ancymidol is the presence of a surfactant in the concentrated solution. Greater penetration of Ancymidol into roots may have occurred since other retardants were applied without surfactants.

Ancymidol may also persist in the soil and in the

plant longer than other retardants. CCC is metabolized to choline and other products (33,75), and SADH is readily leached from plants and soil (6). Amo-1618 is persistent in soil but did not strongly inhibit growth of marigold, salvia or petunia plants.

Seasonal Effects of Retardant Treatment

Ancymidol, like the other retardants examined, was more effective in inhibiting growth in summer than in winter. These results are not unprecedented, Phosfon has been reproted to be more effective in summer (8). To date no hypotheses concerning seasonal variations in retardant effectiveness have been suggested, and it is difficult to cite one cause for the effectiveness of summer treatments. Several factors may be involved. A discussion of these factors follows.

GA has been reported to influence plant responses to photoperiod. GA may even substitute for long days (9,32). GA metabolism may be altered depending on photoperiod (43), and GA synthesis and release of bound GAs may be promoted by light (57). If GA synthesis varies depending on photoperiod, the inhibitory effects of retardants would also be expected to vary since the primary action of retardants is blockage of GA synthesis.

Presence or absence of light may also affect retardant action. CCC is more active in retarding stem elongation in light than in darkness (78). This is interesting because

in many plants dwarfness is manifested only in light (77), and dark-grown seedlings of dwarf strains may be no shorter than normal plants when grown in darkness. Etiolated plants produce less GA than light-grown plants (57) and an absence or reduction of GA synthesis could result in an absence or reduction of the inhibitory effect of growth retardants.

A similar situation may be involved with winter-grown plants. If GA synthesis is reduced in winter due to shorter days and reduced light intensity, less inhibition would follow retardant application.

Stem elongation in winter may depend more on release of GAs from bound forms than stem elongation in summer. Low winter temperatures tend to stimulate the release of bound GAs (43) which could reduce the need for de novo production and reduce plant response to applied retardants.

GA is synthesized in relatively large amounts under high light. If internode elongation is regulated by synthesis of GAs in summer and release of GAs from bound forms in winter, retardants would be more effective in inhibiting internode elongation in summer than in winter.

It should be noted here that control plants were also shorter in summer than in winter. This is not contradictory to the hypothesis that GA production is stimulated in summer, because the inhibitory effect of light on stem growth is thought to be due to inhibition of GA action and not inhibition of GA synthesis (48). Red light inhibits

stem growth of peas (45), which indicates that phytochrome controls GA's role in stem elongation.

Interaction Between Retardants and Phytochrome

Results of the experiments discussed in this paper indicate that light intensity and duration may influence retardant effectiveness. An interaction between retardants and phytochrome may be indicated. There is already strong indirect evidence that retardants may alter phytochrome action.

Phytochrome regulates GA efflux from plastids (57) and may control GA synthesis (77). GA and phytochrome are, at least in part, associated with chloroplast membranes (57). In addition, some phytochrome is associated with the plasmalemma (49, 57). Phytochrome is thought to mediate or control membrane permeability (49,57), ion uptake (49), and ion transport (57). Retardants block GA synthesis and action, and alter membrane permeability (72), ion uptake (1,31,37), and ion transport (5,85). It is quite probable that retardants also affect phytochrome since phytochrome is involved in the same processes which retardants disrupt.

Further indirect evidence of retardant interference with phytochrome action could be delays in flowering which often follow retardant treatment (22,40,41,52,81). However, delayed flowering could also be due to retardant interference with GA's promotive action in flowering. GA promotes bud development, but its role is not clear. It has

been suggested that GA promotes bud development by attractint assimilates (2). If retardants alter carbohydrate translocation, as has been suggested (2), delay of bud development would be a possible consequence, but changes in carbohydrate translocation may also promote flowering (72, 80).

GA and phytochrome are closely associated (57). Since retardants block GA synthesis and action, and are more effective in summer than in winter, it would be interesting to investigate the seasonal effects of retardants on phytochrome levels and activity.

Ion Exchange Resin Treatments

Addition of ion exchange resin treated with Ancymidol to the growing medium was an effective method of controlling height of marigold, salvia and petunia plants. It is doubtful that Ancymidol molecules were ionically bound to the beads, however, because the pH of the concentrated Ancymidol solution was 6.8, indacating little ionization of Ancymidol in the solution. Ancymidol molecules may have been adsorbed to or physically trapped by the beads.

It is likely that some physical binding took place because when excess Ancymidol was filtered off the Ancymidol and resin mixture, the filtrate was clear. The concentrated solution is green. It is not clear whether the green color is added to the concentrated Ancymidol as an indicator or whether the crystalline Ancymidol is green.

Crystalline Ancymidol was not available for comparison. It is likely that the green color is an indicator since the color is dark and the Ancymidol concentration is only 264 ppm, and since the color was readily removed from the solution. In future experiments the filtrate could be applied to plants to test for retardant activity.

The method of amendment of the Ancymidol and ion exchange resin mixture to the soil is probably similar to slow release methods. Due to the large excess of Ancymidol mixed with the beads, Ancymidol molecules were probably released in large amounts initially, followed by a slower release rate over several months. Retardants have previously been reported to be effective when applied slowly over extended periods (20,61,65,66).

It would be interesting to amend an SADH and ion exchange mixture to the growing medium of a plant inhibited by SADH and compare the results to those obtained with Ancymidol. SADH is readily ionized and would bind to anion exchange beads.

Seed Treatments

Depression and Delay of Germination

Germination was reduced or completely suppressed in approximately 35% of the treatments examined. Germination was delayed in approximately 10% of the treatments. Decreases and delays in seed germination following re-

tardant treatment have been previously reported (10). There are several possible explanations for suppressed or delayed germination.

The simplest explanation would be retardant blockage of GA synthesis in germinating seeds. If GA synthesis was blocked, activation of αamylase could not occur, starch reserves could not be broken down, and germination would be inhibited.

Retardants have been reported to reduce respiration (53). Reduced respiration in seeds would also limit starch breakdown and prevent mobilization of breakdown products to the developing embryo, thereby inhibiting germination.

In some cases retardants are thought to reduce cell wall plasticity (10), possibly counteracting GA's role in promoting cell wall loosening prior to cytokinesis. Inhibition of cell wall loosening in germinating seeds would prevent cytokinesis and suppress germination by preventing growth of the embryo.

In some cases interference with GA synthesis or other processes could be temporary, resulting only in delayed germination.

Inhibitory Action of Ancymidol on Plants Grown from Treated Seeds

Seed treatments with growth retardants were largely ineffective in reducing height of plants grown from treated seeds. In most cases no effect of retardant treatment was apparent or seeds failed to germinate. There is apparently a very narrow concentration range over which an inhibitory

effect can be obtained. Growth was inhibited in marigold and salvia plants grown from seeds treated with aqueous solutions of growth retardants, which indicates that direct aqueous seed treatment is a possible method for controlling height of bedding plants.

Inhibition of growth of marigold and salvia plants grown from seeds treated with Ancymidol may have been due to the presence of a surfactant in the concentrated Ancymidol solution. The surfactant may have facilitated penetration of the chemical into seeds. Marigold and salvia seed coats may be more permeable to Ancymidol than those of petunia. However, petunia seeds treated with 132 ppm Ancymidol and washed with distilled water failed to germinate, indicating that uptake had also occurred in these seeds.

Further work with aqueous solutions of Ancymidol is indicated. Seeds could be treated for longer periods at 4°C since germination does not occur at this temperature. Longer treatment may result in greater inhibition of internode elongation in plants grown from treated seeds. It would also be useful to investigate further the optimum concentration of Ancymidol for each plant. Initial results show that marigold seeds can tolerate treatment with 132 ppm Ancymidol, but treatments at or below 13.2 ppm are more appropriate for salvia and petunia seeds.

Acetone Treatments

Acetone seed treatments were not effective in retarding growth of plants grown from treated seeds. However, lateral shoot development was enhanced in all plants treated with acetone, with or without retardants. Lateral branch development was not enhanced in distilled water controls.

It is probable that acetone penetrated salvia seed coats only, because Safranin Red dye added to acetone colored the interior of salvia seeds but not the interior of marigold and petunia seeds. Acetone penetration into salvia seeds could account for sensitivity of salvia seeds to acetone treatment. Most salvia seeds failed to germinate when treated in acetone for longer than one hour. However, lateral branching was increased in marigold, salvia and petunia plants, which leads to the conclusion that the seed coat rather than the embryo was affected by the acetone.

It is possible that an inhibitor was leached from the seed coat by acetone treatment or that some contaminant in the acetone interfered with auxin's role in inhibiting axillary bud development.

Talc Treatments

Talc treatments of seeds with growth retardants did not reduce plant height at flowering. A transitory inhibition was observed in some cases.

If retardant treatment temporarily inhibits GA synthesis but the inhibitory effect is overcome by metabolism of the retardant, GA synthesis could resume, possibly at an accelerated rate. It has been shown that retardants block the synthesis of GA by preventing the cyclization of geranylgeranyl pyrophosphate to kaurene, resulting in a build-up of geranylgeranyl pyrophosphate. GA synthesis could occur at a rapid rate after metabolism or inactivation of the retardant if a pool of geranylgeranyl pyrophosphate was available for conversion into GA.

Indirect Seed Treatments

Cathey has suggested that if a plant is not responsive to retardant treatment it cannot be assumed that growth of the second generation will not be retarded (5). However, the results presented in this paper suggest the opposite, that is, if the retardant is not effective in inhibiting growth of the parent plant, growth of the progeny will not be retarded. In many cases retardation of the parent plant did not even insure retardation in the progeny.

It has been reported that the kinds and amounts of gibberellins in plants are not constant during development (57), and that GA content may vary during seed development. It has also been reported that inhibitors of GA synthesis inhibit the accumulation of GA in seeds (57). The time of retardant treatment of parent plants may therefore affect GA accumulation in the developing seeds. GA content in

mature seeds could influence internode elongation in plants grown from those seeds.

A detailed time course study of seeds treated during different stages of development could indicate optimal stage of seed development for retardant treatment of parent plants. Treatment too early or too late could result in lack of internode elongation inhibition in second generation plants.

Parent plants may require treatment over extended periods. Soil amendment with Ancymidol mixed with ion exchange resin might be a successful method of treatment for parent plants.

It is interesting to note that the optimal developmental stage for dwarfing the parent plants is not the optimal developmental stage for dwarfing the progeny of treated plants. Internode elongation was inhibited most by retardants when plants were young. This is probably because growth inhibition by retardants is dependent on the rate of GA synthesis, which is high during early growth, when cells can respond to GA by dividing as well as elongating (57). Any retardant effect on development of seeds apparently depends on retardant application at later stages of development, probably after the initiation of flower buds.

CONCLUSIONS

Plant Treatments

Ancymidol is more effective than SADH, CCC or Amo-1618 in inhibiting internode elongation of marigold, salvia and petunia plants at the concentrations used. The effectiveness of Ancymidol is probably due to its inhibitory effect on GA synthesis, but may also be due to its interference with cytokinin activity or the presence of a surfactant in the concentrated solution. Inhibitory effects of growth retardants are generally maintained under field conditions.

Retardant treatments are more effective in inhibiting internode elongation in summer than in winter. GA synthesis may be increased in summer due to increased light intensity and duration, and retardant inhibition of internode elongation is dependent on the rate of GA synthesis.

Internode elongation is inhibited more in young plants than in mature plants following retardant treatment. Young plants generally produce more GA than older plants and the primary action of retardants is blockage of GA synthesis.

Since retardant inhibition of growth is influenced by light intensity and duration, an interaction between retardants and phytochrome is indicated. Indirect evidence of retardant influence on phytochrome is delayed flowering following retardant treatment. Further work is indicated concerning the seasonal effects of retardants on phytochrome levels and activity.

Mixing Ancymidol with ion exchange resin and amending the mixture to the soil is an effective method of controlling height of marigold, salvia and petunia plants. This method may be similar to slow release methods of applying chemicals. Ancymidol was probably not ionically bound to the beads because it does not readily ionize, but may have been physically adsorbed to the beads or trapped within the pores of the beads. SADH would readily bind to ion exchange resin and may be more promising for use as a slow release retardant.

Seed Treatments

Several direct seed treatments wiht aqueous solutions of growth retardants reduced height of plants grown from treated seeds, indicating that direct seed treatments may be an effective method of controlling height of some bedding plants. Aqueous solutions of CCC reduced height of marigold plants grown from treated seeds. Aqueous solutions or Ancymidol reduce height of marigold and salvia plants grown from treated seeds. Although growth was not inhibited in petunia plants grown from seeds treated with aqueous solutions of Ancymidol, uptake of Ancymidol by petunia seeds was indicated because washed seeds failed to germinate. Aqueous seed treatments are most effective in inhibiting internode elongation in plants grown from treated seeds when treatments are applied in summer.

Further work with aqueous solutions of Ancymidol is

indicated. Treatment duration at 4°C could be extended and the optimum concentration for seed treatment of each plant could be further investigated.

Direct seed treatments with acetone do not control the height of plants grown from treated seeds. Either no inhibitory effect was observed in plants grown from treated seeds or seeds failed to germinate. Penetration of acetone beyond the seed coat probably does not occur in marigold and petunia seeds but does occur in salvia seeds, as evidenced by penetration of dye into the seeds, and sensitivity of salvia seeds to acetone treatment.

Acetone treatments, with or without retardants, enhance lateral shoot development in marigold, salvia and petunia plants grown from treated seeds. Acetone may leach an inhibitor from the seed coat or a contaminant may have been introduced in the acetone.

Talc seed treatments do not reduce the flowering height of plants grown form treated seeds. A transitory inhibition may occur, followed by a stimulation of growth. The stimulation may be due to an accumulation of geranyl-geranyl pyrophosphate, which is rapidly converted to GA after metabolism or inactivation of the retardant.

Indirect seed treatments by treatment of parent plants are largely ineffective in inhibiting growth of second generation plants. However, further work is indicated to establish optimal treatment time. Slow release methods of applying retardants may be a useful means of treating

parent plants over long periods. Extended treatments may insure maximum inhibition in second generation plants.

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APPENDIX

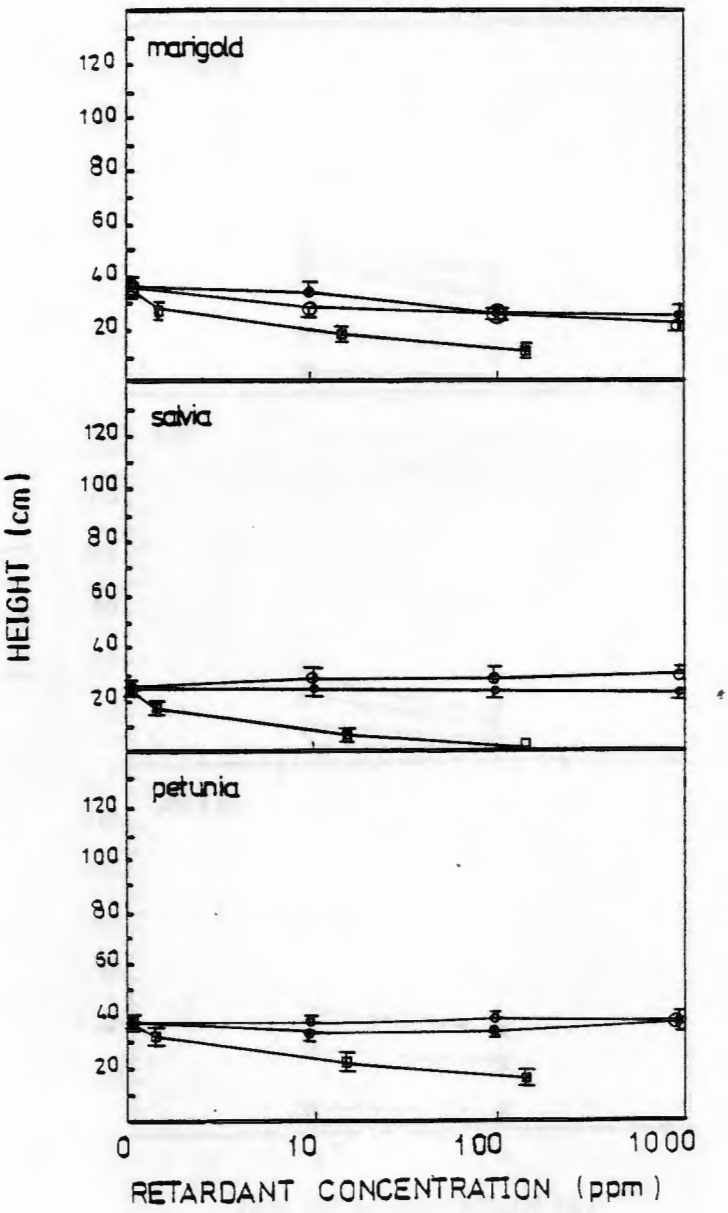

Figure 1. Height of marigold, salvia and petunia plants one month after treatment with SADH (●—●), CCC (o—o) or Ancymidol (□—□) (field study).

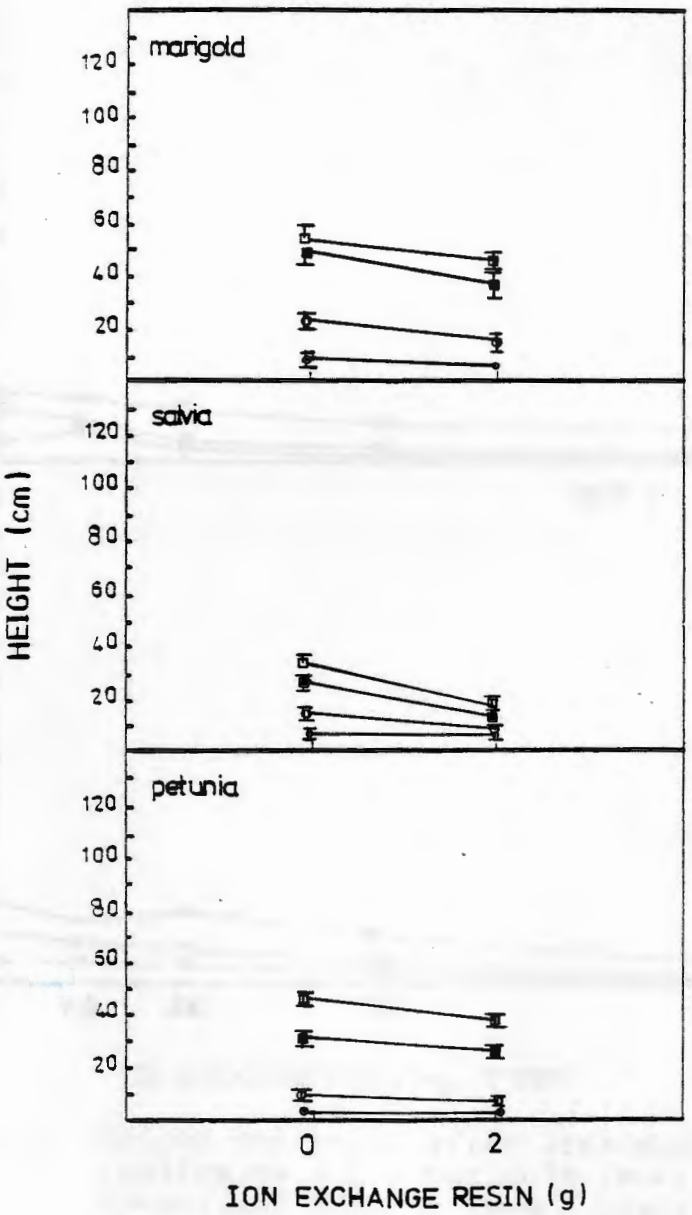

Figure 2. Height of marigold, salvia and petunia plants treated with Ancymidol mixed with ion exchange resin amended to the growing medium two (•—•), four (o—o), six (■—■) and 8 (□—□) weeks after treatment.

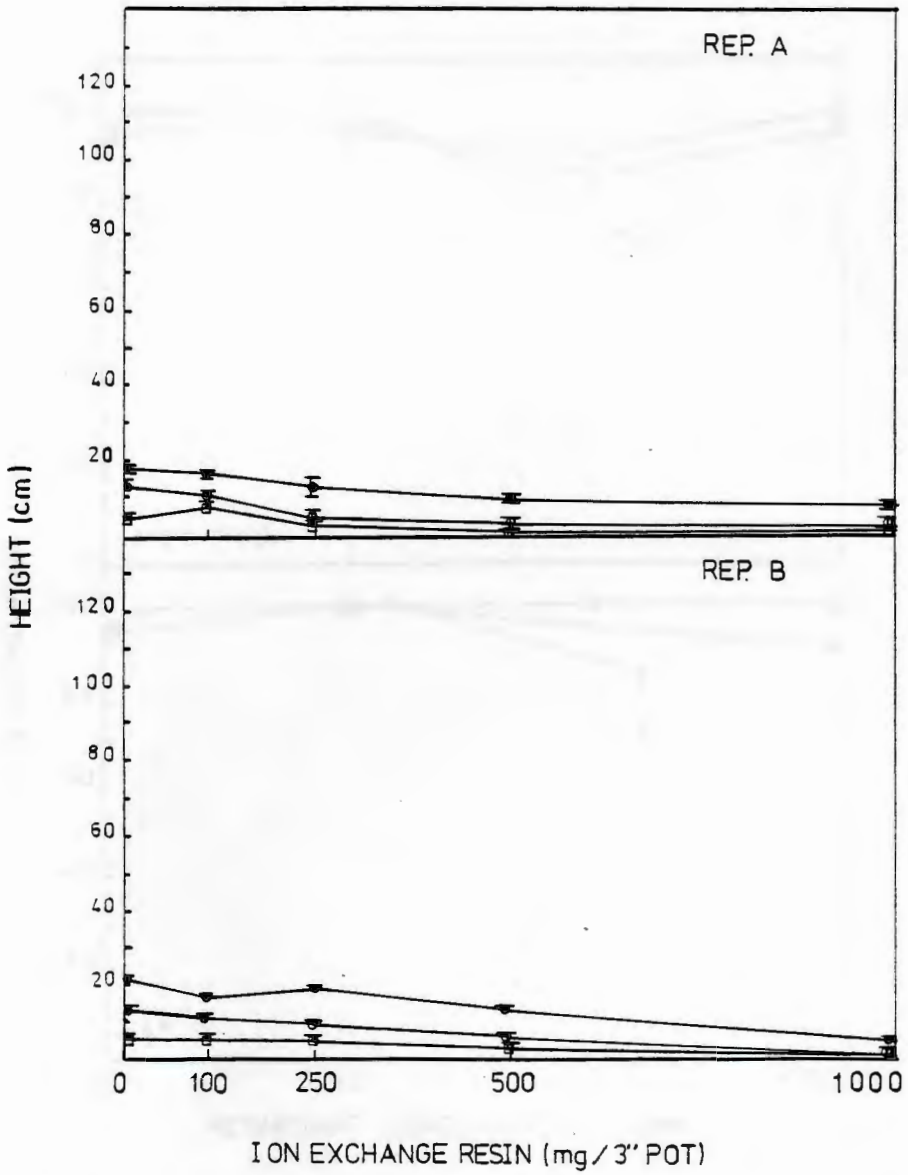

Figure 3. Height one month after treatment of replicates A & B marigold (●—●), salvia (○—○) and petunia (□—□) plants treated with Ancymidol mixed with ion exchange resin amended to the growing medium.

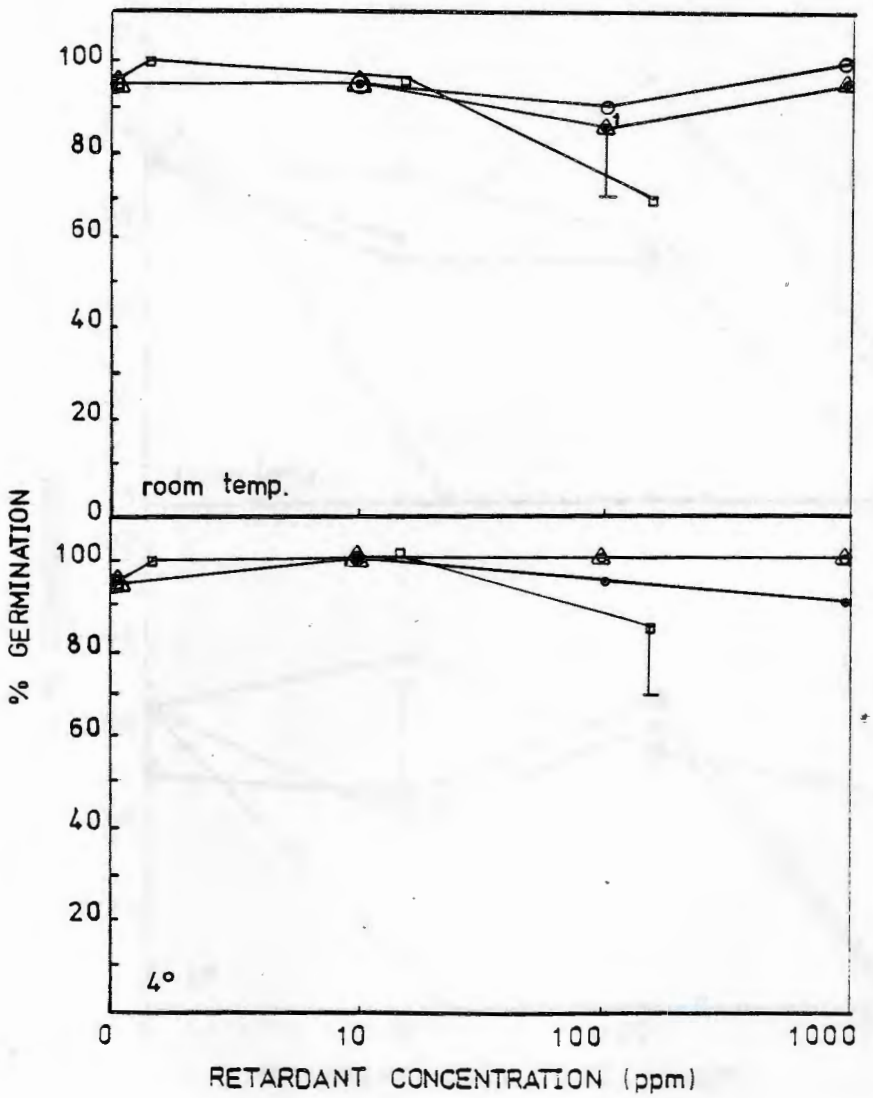

Figure 4. Percent germination of marigold seeds treated with Aqueous solutions of SADH (●—●), CCC (o—o) Amo-1618 (■—■) or Ancymidol at room temperature or 4°C.

(Points falling on percentage values ending with 5 have 5% standard error, values ending in 0 have 0% standard error, unless otherwise indicated.)

1. Standard error 15% for Amo-1618 only.

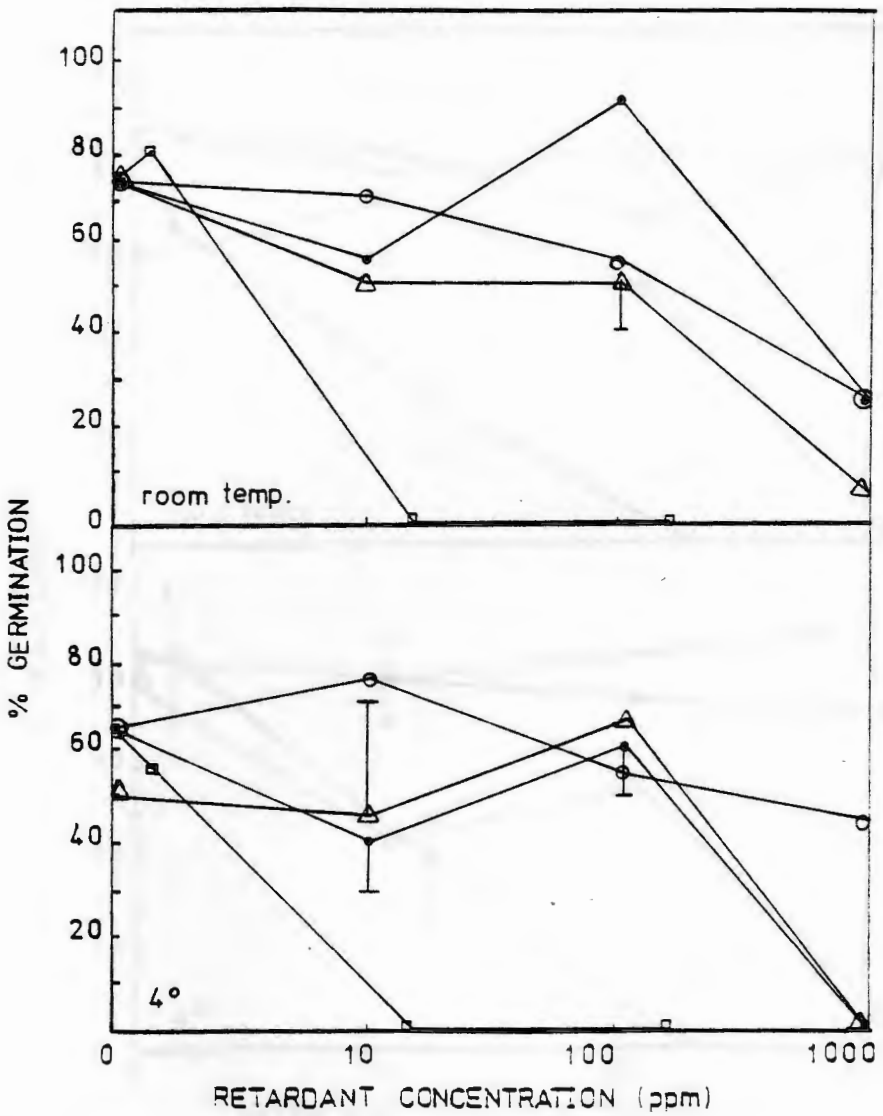

Figure 5. Percent germination of salvia seeds treated with aqueous solutions of SADH (●—●), CCC (○—○), Amo-1618 (■—■) or Ancymidol (□—□) at room temperature and 4°C.

(Points falling on percentage values ending with 5 have 5% standard error, values ending in 0 have 0% standard error, unless otherwise indicated.)

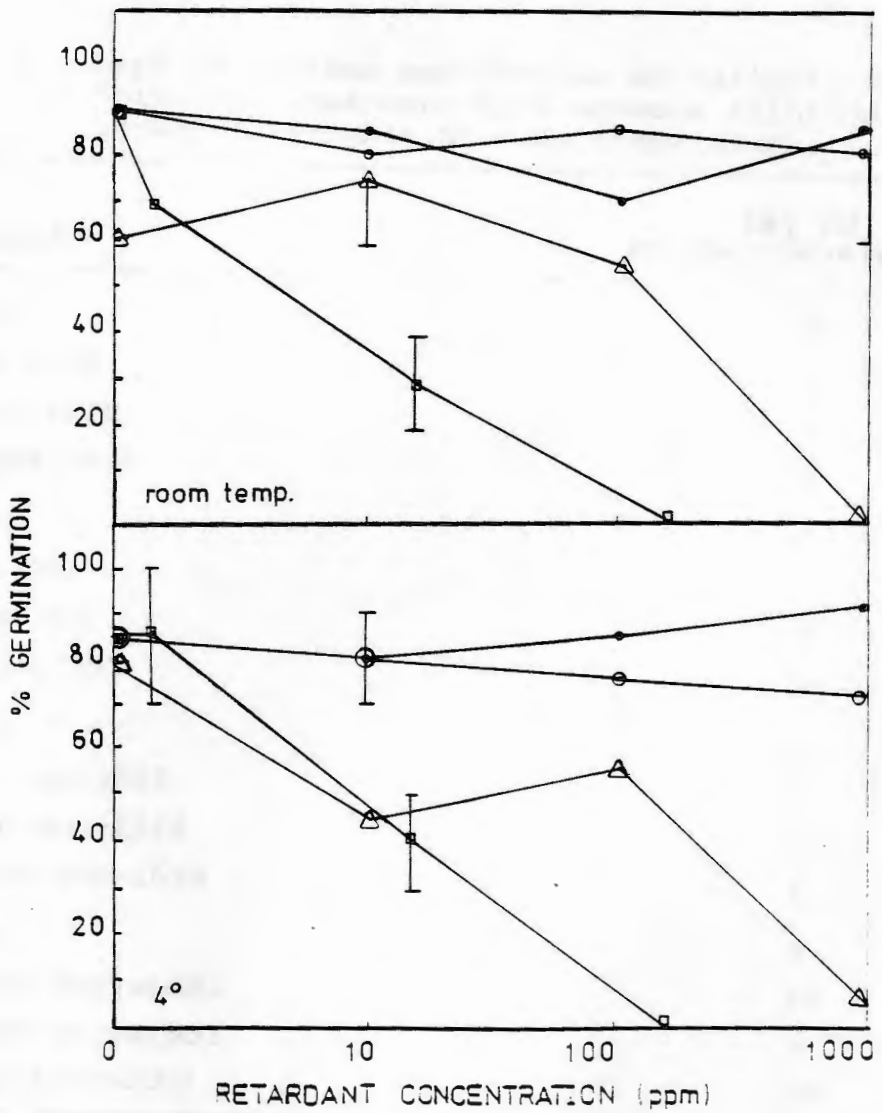

Figure 6. Percent germination of petunia seeds treated with aqueous solutions of SADH (●—●), CCC (○—○), Amo-1618 (■—■), or Ancymidol (□—□), at room temperature and 4°C.

(Points falling on percentage values ending with 5 have 5% standard error, values ending in 0 have 0% standard error, unless otherwise indicated.

Table 1. Days of maximum germination of marigold seeds following treatment with aqueous solutions of growth retardants at room temperature.

Treatment	Day of Maximum Germination
Control	3
10 ppm SADH	3
100 ppm SADH	3
1000 ppm SADH	3
Control	3
10 ppm CCC	3
100 ppm CCC	3
1000 ppm CCC	3
Control	2
10 ppm Amo-1618	2
100 ppm Amo-1618	2
1000 ppm Amo-1618	2
Control	3
1.32 ppm Ancymidol	2[a]
13.2 ppm Ancymidol	3
132 ppm Ancymidol	5[b]

[a]Not significantly different from day 3.

[b]Not significantly different from day 4 but significantly different from day 3.

Table 2. Days of maximum germination of marigold seeds following treatment with aqueous solutions of growth retardants at 4°C.

Treatment	Day of Maximum Germination
Control	3
10 ppm SADH	3
100 ppm SADH	3
1000 ppm SADH	3
Control	3
10 ppm CCC	3
100 ppm CCC	3
1000 ppm CCC	3
Control	3
10 ppm Amo-1618	3
100 ppm Amo-1618	3
1000 ppm Amo-1618	3
Control	3
1.32 ppm Ancymidol	3
13.2 ppm Ancymidol	3
132 ppm Ancymidol	4[a]

[a]Significantly different from day 3.

Table 3. Days of maximum germination of salvia seeds following treatment with aqueous solutions of growth retardants at room temperature.

Treatment	Day of Maximum Germination
Control	3
10 ppm SADH	3
100 ppm SADH	3
1000 ppm SADH	3
Control	3
10 ppm CCC	5[a]
100 ppm CCC	5[b]
1000 ppm CCC	5[b]
Control	4[c]
10 ppm Amo-1618	3
100 ppm Amo-1618	4[c]
1000 ppm Amo-1618	7[d]
Control	3
1.32 ppm Ancymidol	3
13.2 ppm Ancymidol	-
132 ppm Ancymidol	-

[a]Not significantly different from day 4 or day 3.

[b]Not significantly different from day 4 but significantly different from day 3.

[c]Not significantly different from day 3.

[d]Not significantly different from day 6 but different from day 5.

Table 4. Days of maximum germination of salvia seeds following treatment with aqueous solutions of growth retardants at 4°C.

Treatment	Day of Maximum Germination
Control	4
10 ppm SADH	4
100 ppm SADH	4
1000 ppm SADH	-
Control	4
10 ppm CCC	4
100 ppm CCC	5[a]
1000 ppm CCC	5[b]
Control	4
10 ppm Amo-1618	4
100 ppm Amo-1618	4
1000 ppm Amo-1618	-
Control	4
1.32 ppm Ancymidol	4
13.2 ppm Ancymidol	-
132 ppm Ancymidol	-

[a]Significantly different from day 4.

[b]Not significantly different from day 4.

Table 5. Days of maximum germination of petunia seeds following treatment with aqueous solutions of growth retardants at room temperature.

Treatment	Day of Maximum Germination
Control	3
10 ppm SADH	3
100 ppm SADH	3
1000 ppm SADH	3
Control	3
10 ppm CCC	3
100 ppm CCC	3
1000 ppm CCC	4[a]
Control	3
10 ppm Amo-1618	3
100 ppm Amo-1618	3
1000 ppm Amo-1618	-
Control	3
1.32 ppm Ancymidol	5[b]
13.2 ppm Ancymidol	6[c]
132 ppm Ancymidol	-

[a]Not significantly different from day 3.

[b]Not significantly different form day 4 but significantly different from day 3.

[c]Significantly different from day 5, day 4 and day 3.

Table 6. Days of maximum germination of petunia seeds following treatment with aqueous solutions of growth retardants at 4°C.

Treatment	Day of Maximum Germination
Control	4
10 ppm SADH	4
100 ppm SADH	4
1000 ppm SADH	4
Control	4
10 ppm CCC	4
100 ppm CCC	4
1000 ppm CCC	4
Control	3
10 ppm Amo-1618	3
100 ppm Amo-1618	3
1000 ppm Amo-1618	7[a]
Control	4
1.32 ppm Ancymidol	5[b]
13.2 ppm Ancymidol	5[b]
132 ppm Ancymidol	-

[a]Not significantly different from day 3.

[b]Significantly different from day 4 and day 3.

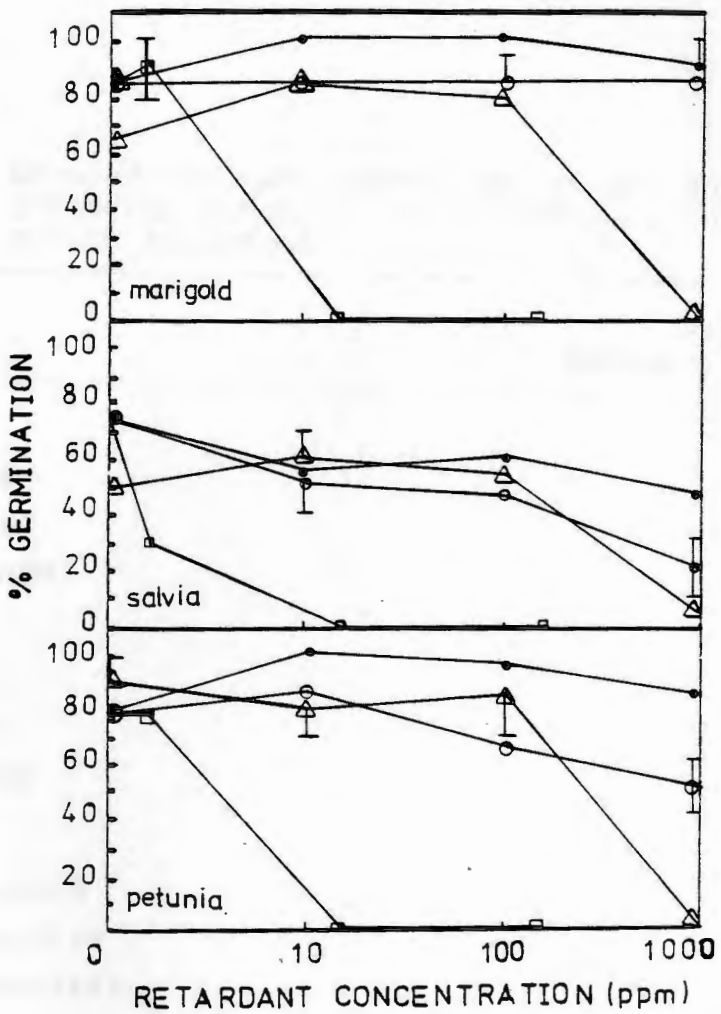

Figure 7. Percent germination of marigold, salvia and petunia seeds treated with acetone solutions of SADH (●—●), CCC (○—○), Amo-1618 (■—■), or Ancymidol (□—□).

(Points falling on percentage values ending with 5 have 5% standard error, values ending in 0 have 0% standard error, unless otherwise indicated.)

Table 7. Days of maximum germination of marigold seeds following treatment with acetone solutions of growth retardants.

Treatment	Day of Maximum Germination
Control	3
10 ppm SADH	3
100 ppm SADH	3
1000 ppm SADH	3
Control	3
10 ppm CCC	3
100 ppm CCC	3
1000 ppm CCC	3
Control	3
10 ppm Amo-1618	3
100 ppm Amo-1618	3
1000 ppm Amo-1618	3
Control	3
1.32 ppm Ancymidol	3
13.2 ppm Ancymidol	3
132 ppm Ancymidol	3

Table 8. Days of maximum germination of salvia seeds following treatment with acetone solutions of growth retardants.

Treatment	Day of Maximum Germination
Control	3
10 ppm SADH	3
100 ppm SADH	3
1000 ppm SADH	3
Control	3
10 ppm CCC	3
100 ppm CCC	3
1000 ppm CCC	3
Control	3
10 ppm Amo-1618	3
100 ppm Amo-1618	3
1000 ppm Amo-1618	4[a]
Control	3
1.32 ppm Ancymidol	4[a]
13.2 ppm Ancymidol	-
132 ppm Ancymidol	-

[a]Not significantly different from day 3.

Table 9. Days of maximum germination of petunia seeds following treatment with acetone solutions of growth retardants.

Treatment	Day of Maximum Germination
Control	4
10 ppm SADH	4
100 ppm SADH	4
1000 ppm SADH	4
Control	4
10 ppm CCC	4
100 ppm CCC	4
1000 ppm CCC	5[a]
Control	3
10 ppm Amo-1618	3
100 ppm Amo-1618	3
1000 ppm Amo-1618	-
Control	4
1.32 ppm Ancymidol	-
13.2 ppm Ancymidol	-
132 ppm Ancymidol	-

[a]Significantly different from day 4.

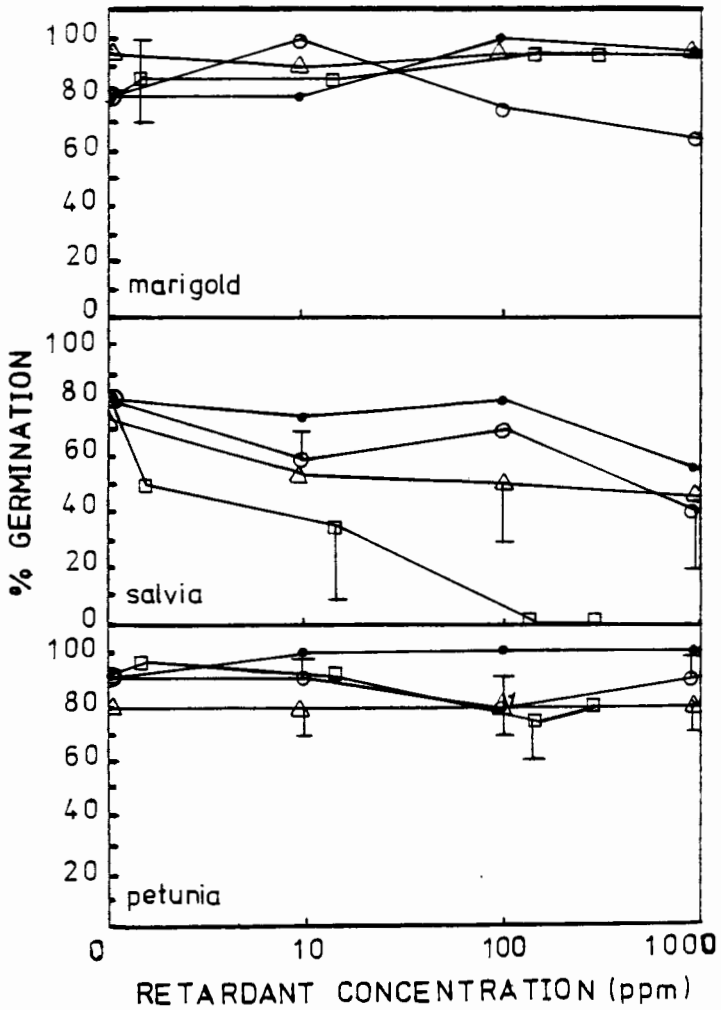

Figure 8. Percent germination of marigold, salvia and petunia seeds treated with talc formulations of SADH (●—●), CCC (○—○), Amo-1618 (■—■) or Ancymidol (□—□).

(Points falling on percentage values ending with 5 have 5% standard error, values ending in 0 have 0% standard error, unless otherwise indicated.)

1. 10% standard error for 100 ppm Amo-1618 and 100 ppm CCC.

Table 10. Days of maximum germination of marigold seeds following treatment with talc formulations of growth retardants.

Treatment	Day of Maximum Germination
Control	2
10 ppm SADH	2
100 ppm SADH	3[a]
1000 ppm SADH	3[b]
Control	2
10 ppm CCC	2
100 ppm CCC	2
1000 ppm CCC	2
Control	2
10 ppm Amo-1618	2
100 ppm Amo-1618	2
1000 ppm Amo-1618	2
Control	2
1.32 ppm Ancymidol	2
13.2 ppm Ancymidol	2
132 ppm Ancymidol	2
264 ppm Ancymidol	3[a]

[a]Not significantly different from day 2.

[b]Significantly different from day 2.

Table 11. Days of maximum germination of salvia seeds following treatment with talc formulation of growth retardants.

Treatment	Day of Maximum Germination
Control	2
10 ppm SADH	3[a]
100 ppm SADH	3[a]
1000 ppm SADH	3[b]
Control	2
10 ppm CCC	2
100 ppm CCC	3[a]
1000 ppm CCC	2
Control	2
10 ppm Amo-1618	2
100 ppm Amo-1618	2
1000 ppm Amo-1618	2
Control	2
1.32 ppm Ancymidol	2
13.2 ppm Ancymidol	2
132 ppm Ancymidol	-
264 ppm Ancymidol	-

[a]Significantly different from day 2.

[b]Not significantly different from day 2.

Table 12. Days of maximum germination of petunia seeds following treatment with talc formulations of growth retardants.

Treatment	Day of Maximum Germination
Control	2
10 ppm SADH	2
100 ppm SADH	2
1000 ppm SADH	2
Control	2
10 ppm CCC	2
100 ppm CCC	2
1000 ppm CCC	2
Control	2
10 ppm Amo-1618	2
100 ppm Amo-1618	2
1000 ppm Amo-1618	2
Control	2
1.32 ppm Ancymidol	2
13.2 ppm Ancymidol	2
132 ppm Ancymidol	2
264 ppm Ancymidol	3[a]

[a]Significantly different from day 2.