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I am submitting herewith a dissertation written by Fadhil M. Humadi entitled "Effects of Plant Growth Retardants and Mechanical Topping on Growth and Yield of Pimiento Pepper (Capsicum annuum L.)." I recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Plant and Soil Science.

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EFFECTS OF PLANT GROWTH RETARDANTS AND MECHANICAL TOPPING ON GROWTH AND YIELD OF PIMIENTO PEPPER (*Capsicum annuum* L.)

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ABSTRACT

The effects of growth retardants and mechanical topping were studied on pimiento pepper (*Capsicum annuum* L.).

In greenhouse studies, N-dimethylamino succinamic acid (Daminozide) and (2-chloroethyl) trimethylammonium chloride (CCC) at concentrations of $5x10^{-2}$, $1x10^{-2}$, $5x10^{-3}$, and $1x10^{-3}$M were applied to pimiento peppers (cv. Truhart Perfection) at seed, 2-leaf, 4-leaf, and two or three times repeated stages. CCC and Daminozide at most concentrations and times of applications were effective in increasing root length and retarding plant height. The action of these growth retardants on plant height was specific on inhibiting internodal elongation in the sub-apical region. Both retardants at most concentrations applied resulted in an increase in stem diameter. CCC was more effective than Daminozide in increasing stem diameter. Foliar application of the retardants at all concentrations and times studied resulted in an enhancement of the green color of the plant foliage. Time from transplanting to flowering was shortened by approximately 7-16 days by growth retardants. CCC was more effective than Daminozide in increasing both marketable and total yield. At all concentrations and times of applications, both retardants increased the leaf content of Mg and K and had no effect on the content of N, P, and Ca.

Mechanical topping and retardant treatments were studied in the field. Retardants increased both the early and the total yield of ripe fruits. Fruits from treated plants started to ripen about 12 days

earlier than normal, a response which would be advantageous to growers of pimientos. Plants topped 1 or 2 times to a height of 23 cm yielded more ripe fruits at the first harvest than untopped plants. Seasonal yields were not influenced by topping.

Results from these studies indicate that CCC and Daminozide may be used to facilitate the mechanical transplanting of pimiento. Retardants applied at the seedling stage appear useful in preventing the development of oversized plants, a problem which is often encountered in the commercial production of pimiento transplants.

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CHAPTER I

INTRODUCTION

Pimiento peppers (*Capsicum annuum*) belong to the Solanaceae or nightshade family and are therefore closely related to eggplant, tomato and potato. They thrive best in a relatively warm climate and require a long season to mature their fruits. Because of their brilliant red fruit color and flavor characteristics, ripe pimientos are widely used as a processed condiment in many foods. In addition to their attractive and flavorful qualities, their exceptionally high content of vitamins A and C deserves consideration in assessing pimiento's value as a food (5,19).

The major commercial production of pimiento peppers has been in the south central states of Alabama, Georgia and Tennessee. Considerable production of pimiento peppers is now concentrated in the southern and western portions of Tennessee. Estimates by Marshall (37) in 1976, of harvested acreage, production and grower value for peppers ranks Tennessee second in the U.S. with harvest acreage, production in tons and grower value in dollars of 2200, 7700 and 1,540,000, respectively. Many of the growers in Tennessee have rather small enterprises of an acre or less and depend heavily on family labor in the production operations, especially harvesting.

At present most of the pimiento acreage is established from transplants. One of the major problems in pimiento production is the availability of plants for transplanting to the field sufficiently early in the season. For this reason, Tennessee growers must depend on transplants imported from more southerly growing areas. In the vegetable plant-growing area in South Georgia, the open-field method of growing pimiento plants has been used successfully. More recently, pimiento processors have grown a considerable quantity of these plants in Central Florida. The open-field method of growing pimiento transplants has some advantages; however, in some years unfavorable weather conditions in areas of production delay the transplanting operation (18). The transplants become too large, nonuniform, and therefore are difficult to plant with mechanical transplanters.

Pimiento peppers, generally, must be completely red to be acceptable for processing. This requires a long growing season and an extended harvest period. It would be advantageous to growers for processing to have fruits ripen earlier and more uniformly than is possible with current cultivars and cultural practices. Earlier and more uniform ripening would facilitate a single mechanical harvest or few successive hand harvests. Since mechanized harvesting is on the horizon for pimiento and other types of peppers, much effort is being devoted to developing and/or breeding plants that lend themselves to a single destructive harvest.

To meet the requirements for a single mechanized harvest and to reduce the necessity for repeated hand harvests of pimiento, morphological characteristics of size and shape and physiological characteristics of flowering, fruit development and ripening of present cultivars must be altered. Of course, this must be accomplished without reducing subsequent yields. This research was devoted to effecting favorable changes in some of the above morphological and physiological characteristics through the use of plant growth retardants. However, any physiological or chemical treatment that is capable of inducing earlier yields or increasing the total yields of pimiento peppers could be of considerable importance to the vegetable industry. For this reason, an experiment was designed to study the effect of two different growth retardants, (2-chloroethyl) trimethylammonium chloride (CCC) and N-dimethyl amino succinamic acid (Daminozide), on pimiento pepper (cv. Truhart Perfection) applied at the seed and seedling stages.

The effect of different topping regimes of pimiento transplant upon growth and yield was also studied.

CHAPTER II

LITERATURE REVIEW

Synthetic organic chemicals which retard stem elongation, increase green color, and indirectly affect flowering without causing malformation of the plants have been introduced since 1949 and have proved to be valuable tools to control plant size (77). These compounds which slow cell division and cell elongation in shoot and control height of the plant without causing stem bending or leaf malformation are named growth retardants. Growth of treated plants is not completely suppressed and neither rate of organ development nor vigor is affected. These characteristics separate growth retardants from such synthetic growth inhibitors as maleic hydrazide (1,2-dihydro pyradzine-3,6 dione), which suppresses cell division in the apical meristem.

The physiological action required for a chemical to be a growth retardant excludes many kinds of growth regulators, such as auxins, herbicides of the growth regulator type, and germination inhibitors (12). Most auxins in supraoptimal concentrations inhibit plant growth, but they also cause visible malformations of the leaves, stems, and plant habit. Suboptimal concentrations of herbicides generally inhibit the expansion of all plant parts, often producing plants that are miniatures of untreated plants. Eventually, the plants resume normal growth. Herbicides usually cause some foliar damage, disfiguring the plant permanently. Germination inhibitors are relatively nonspecific as to the number of species they affect. They may be naturally occurring or synthetic and are active on germinating seeds or seedlings but are rarely active on mature plants.

I. History of Growth Retardants

In 1949, Mitchell, Wirwille and Weil (43) reported that the first plant growth retardants discovered were nicotiniums which were found to reduce stem elongation of bean plants without gall formation or other formative changes. The most active compound was 2,4-dichlorobenzyl-nicotinium chloride, designated 2,4 DNC[1-(2,4-dichlorobenzyl)-1-methyl-2(3-pyridyl, pyrrolidinium chloride)]. The above workers also reported that picolinium and pyridinium, quaternary ammonium compounds of coal tar derivation, were active on bean plants.

In 1950, Wirwille and Mitchell (84) reported that a series of quaternary ammonium carbamates retarded growth of snapbeans under greenhouse conditions, without causing malformation of leaves, stems, roots, or flowers. The most active compound in this group was 4-hydroxyl-5-isopropyl-2-methylphenyl trimethyl ammonium chloride, 1-piperidine carboxylate, designated Amo-1618. The compounds such as morpholinium, quinaldinium, piperidinium, quinolinium, and a substituted hydrazine, were shown to be growth retardants on snap beans and cucumber (12).

Gowing and Leeper (22), in 1955, showed that B-hydroxyethyl hydrazine, designated BOH, induced early flowering in pineapple. The first action of the chemical was to retard stem elongation. In the same year, the growth-retarding effects of the phosphoniums were first reported on cucumber plants where treated plants developed internodes much shorter than those of untreated plants (12).

In 1960, a new group of quaternary ammonium compounds was reported by Tolbert (71). The most active compound, (2-chlorethyl) trimethyl ammonium chloride, was an analog of choline, in that the hydroxy group in choline was replaced with a chlorine substitutent. Its trival name was chlorocholine chloride, hereafter referred to as CCC. The compound retarded the growth of a larger number of species than any of the earlier compounds.

Riddell et al. (54), in 1962, reported that application of sprays of substituted maleamic and succinamic acids to foliage retarded the growth of legumes, vine crops, potatoes, and ornamental plants. The most active compounds were N-dimethylamino maleamic acid (C011) and N-dimethylamino succinamic acid hereafter referred to as Daminozide.

Tolbert (71), as mentioned above, showed the existence of a series of quaternary ammonium compounds. The most active compound was CCC and it was considered an analog of choline with the general formula of the cation $CH_2X\text{-}CH_2\text{-}N^+\text{-}(CH_3)_3$. The trimethyl quaternary ammonium cation was necessary for activity, any substitution for even one methyl group produced nearly inactive compounds. For optimal activity, the carbon chain compounds were active when the substituents at "X" were small, nucleophilic, and nonionizable. The corresponding tributyl or triethyl derivatives of CCC (2-chloroethyl) triethyl ammonium chloride, were completely inactive on wheat seedlings. The bromide and chloride salts are active compounds.

Daminozide, N-dimethylamino succinamic acid, is unique in its chemical structure as a growth retardant. It does not contain a benzene ring, quaternary ammonium or phosphonium cation, or substituents that are of small size, nucleophilic, and nonionizible (54). The compound is a free, ionizable acid with C-C-N-N system found in B-hydroxyethyl hydrazine (BOH) and maleic hydrazide. The metal and alkanolamine salts of Daminozide were readily formed and functioned as growth retardants. Table 1 includes the chemical structure and activity of 4 of the most important growth retardants, Daminozide, CCC, Amo 1618, and Phosphon.

II. Effect of Growth Retardants on Plants

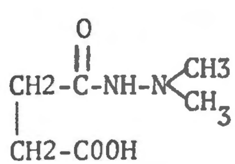
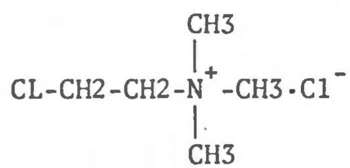
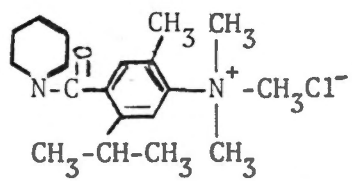
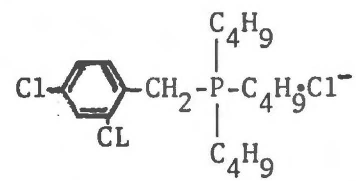
Root Development

The growth retardant (2-chloroethyl) trimethylammonium chloride "CCC" induced swollen root tips on seedlings of grapevines (*Vitis Vinifera* L.) when applied to the growth medium as well as on plants grown from cuttings (64). It is probable that CCC acts on the root meristem to increase cytokinin production and that the latter compound causes the root tip to swell. Increased amounts of cytokinins are also found in plant sap as a result of application of CCC to the roots (77).

Read and Hoysler (50), in 1969 reported that B-9 increased adventitious root formation in geranium, chrysanthemum, and dahlia cuttings while CCC had a retarding effect. On the other hand, root-hypocotyl axes of zinnia subjected to Alar at a concentration of 500 ppm resulted in retardation of root-hair initiation (39).

Joshi (31) in 1978 found that pimiento peppers treated with two retardants showed more extensive development of root systems than untreated plants. Plants treated with CCC had bigger root systems than those treated with SADH.

Table 1. Chemical Name, Structure, and Selected Characteristics of Daminozide, CCC, Amo-1618, and Phosphon.

Characteristic	Daminozide	CCC	Amo-168	Phosphon
Molecular Weight	160	158	358	378
Persistance in Soil	3-4 weeks	3-4 weeks	At least 10 years	More than 1 year
Response to Concentrations	High requirement; response to a plateau over wide dosage range; no toxicity	High requirement; range from no response to toxicity symptoms	Gradual height reduction with increasing concentrations	Gradual height reduction with increasing concentrations; toxicity symptoms at high concentrations
Spray application	Highly effective	Relatively effective	Highly effective	Toxic, chlorophyll destroyed
Chemical name	N-dimethylamino succinamic acid	(2-chloroethyl) trimethyl ammonium chloride	4-Hydroxyl-5-isopropyl-2-methyl- phenyl trimethyl ammonium chloride, 1-piperidine carboxylate	2,4-dichlorobenzyl-tributyl phosphonium chloride
Trade name	Alar, B-9, B-995	Cycocel	--------	Phosphon
Chemical structure				

Cotton plants treated with CCC showed better developed root systems than untreated plants (15). SADH at 2500 ppm and chlormequat at 1500 ppm increased number and size of tuberous roots of dahlias under short-day conditions (51). Plants grown from roots of treated plants were of excellent size, color, and quality.

Most other researchers working with retardants have reported that root system of treated plants are less developed than those of untreated plants and the ratios of top to root are reduced (12).

Shoot Elongation

It has been reported by several workers that the most characteristic growth change as a result of treatment with growth retardants is a reduction in height of plants. Dwarfing is due to shortening the internodes.

When the growth retardant, cycocel, was applied to young tomato plants when they attained the 3 true leaf stage, it was effective in reducing growth regardless of the fertility level (33). Controlling tomato transplant height with growth retardants was also found by Pisarczyk and Splittstoesser (47,48). They found that Daminozide and CCC inhibited increases in tomato transplant height for two weeks.

In 1962, Tiessen (70) working with tomato and peppers applied aqueous solutions of CCC and (allyl) trimethylammonium bromide (AMAB), at concentrations of 10^{-3} and 10^{-4}M to either the foliage or to the root medium. They found that drench applications of 100 milliliters per 4-inch band to tomatoes and 900 milliliters per square foot to peppers of 10^{-3} and 10^{-4}M solutions of CCC or of AMAB produced shorter, stockier, darker-green plants with reduced foliage spread. The same results were found on tomato plants by Wittwer and Tolbert (85) when they used 10^{-3} to 10^{-7}M solutions of CCC. The growth response varied from a stimulation at 10^{-7}M to a marked suppression at 10^{-4}M without delay of flowering or visible injury. Top-to-root ratios were also reduced by the growth retardant. The growth changes were similar to those produced by exposure to high light intensities and low temperature. In 1974, Read et al. (52) found with CCC drenched or sprayed tomatoes, normal internode elongation is sharply reduced. In contrast, the gradual uptake from an encapsulated formulation of CCC results in a more symmetrical plant with internode elongation controlled at a steady rate. Higher levels of encapsulated CCC (12-25 g/liter) retarded plant height to 50% of that of the controlled and produced stocky, more symmetrical bedding plants without deleterious effects. The greatest reduction in tomato plant height was also found with application of Alar (11,68).

On pimiento peppers, Joshi (31) found that CCC and SADH were effective in limiting plant height and they were more effective at the early stage of plant growth. A foliar concentration of 10^{-3}M CCC had a stronger effect than a similar concentration of SADH or a drench treatment at the early stage of plant growth. Wilbert and Nakayama (80), in 1968, reported a significant reduction in stem length of chili pepper 14 and 21 days after foliar applications of Alar at 1000 and 10000 ppm.

It was reported by Tompkins and Norton (73) that plant height of Brussels sprouts was retarded by foliar sprays of 3000 to 6000 ppm of

Alar. They observed also that Alar treated plants did not have to be hand topped because the chemical stopped stalk elongation. Sherman and Hillyer (63) treated lettuce plants with B-9 and found that plant height was significantly reduced by the 10,000 and 15,000 ppm treatment at the 8-leaf and 4 and 8 leaf stage. The 15,000 ppm showed the greatest reduction in plant height.

In lettuce, a facultative long day plant, CCC was found to suppress plant elongation in light and dark (86). Vegetative extension of genetically dwarf and normal plants was also suppressed by CCC.

Adedipe et al. (3), in 1969, observed that CCC at 100 ppm decreased plant height, internode length and total dry matter of pea plants, but had no significant effect on yield.

Wheat plants treated with CCC at concentrations of 10^{-2} to 10^{-6}M at 2-leaf stage had shorter stems than untreated plants (72). Chauhan and Verman (15) reported that application of CCC as a foliar spray on cotton suppressed excessive vegetative growth in very vigorous varieties.

Treatment of Pharbitis nil Chois with CCC resulted in short, thick internodes and dark green leaves (89). It was suggested by Zeevaart (89) that the differences in the length of the first internode of control plants and those of plants treated with CCC were due only to differences in cell number. CCC reduced mitotic activity, at least, in the first internode.

CCC and Daminozide are usually recommended to reduce plant height in pot plants, nursery crops, and fruit trees since leaf and flower initiations are not severely delayed (46,60,61,74). In most species only internode length is inhibited as a result of reduced subapical meristematic activity.

Stem Diameter

Several researchers have reported an increase in stem diameter from growth retardant treated plants (31,52,62,70,72,85,89).

Tiessen (70) in 1962, reported an increase in stem diameter of tomato and pepper plants from foliar and drench application of CCC. Read et al. (52) found the doubling of stem diameter of tomato when the plants were treated with encapsulated cycocel. Joshi (31) reported that CCC was more effective than SADH in increasing the diameter of the stem in pimiento peppers. Thicker stems were found also in wheat plants treated with cycocel (72,85).

Pith parenchyma cells in Pharbitis seedlings treated with CCC had a larger diameter than those from untreated plants (89). Scherff (62) showed that in bean stems the increase in stem diameter was due to the stimulation of cell production in the cambium, accompanied by a delay in cell differentiation to an increase in cell volume of the parenchymatous cortical cells.

Flower Initiation

Growth retardants apparently promote flowering by modifying the activity in the cambium (12). This results in an abnormal type of cells in the xylem and the disappearance of sclerenchymatous cells adjacent to the cortex. The restriction of growth presumably alters the metabolism and creates conditions conductive to flower initiation.

Low rates (3-6 g of 1,2 or 4% active ingredients/liter of growing medium) of encapsulated CCC stimulated earlier bloom in tomatoes, petunia, snapdragon, and marigold plants up to 14 days over untreated plants (52).

On certain woody plants, the time of flower initiation was greatly accelerated from treatment with growth retardants. Stuart (67) first demonstrated that applications of CCC and B-995 caused suppression of vegetative growth and promoted initiation of flower buds in Rhododendron. These responses were not dependent on minimum age or size of plant, specific photoperiod, or temperature. Chemical growth retardants, CCC and B-9, applied to azaleas stopped vegetative growth, induced flower bud formation (30,40), and increased flower number (41,57). Zeevaart (89) found that CCC promoted early flowering in Pharbitis nil, a short-day plant, under long days. Retarding plant height of geranium plants treated with CCC resulted in promoting of earlier flowering (25,78). Treated plants were shorter, flowered earlier, and were more compact than untreated plants.

Acceleration of flowering has also been reported in herbaceous plants. Control of vegetative growth by CCC and SADH during the early stages of plant growth had a significant influence on the subsequent development of earlier flowering and increased number of flowers produced and fruits set in pimiento peppers (31). Tomato seedlings treated in the cotyledon stage with CCC flowered earlier and produced a larger number of flowers in the first inflorescence than untreated plants (2,85,86). These results were found to be similar to those produced by exposure of the plants to intense light and low temperature. Coyne (16) found that CCC promoted early flowering in the short-day bean under long days. CCC treated plants flowered as early as the control plants grown under short-day conditions.

According to Cathey (12), Jaffee and Isenberg reported that sweet corn produced more ears per plant with increasing dosages of B-995.

Abdel-Gawad and Ketellapper (1) found that CCC at 2000 ppm under short day conditions, retarded growth, delayed plant senescence and enhanced the appearance of the first pistillate flower at lower node in squash plants. On the other hand, SADH effectively increased female tendency of muskmelon plants (56).

Yield

Tukey and Fleming (75) demonstrated that the yield of 'Concord' grapes was increased from the application of Daminozide from 1-50% bloom. Similar results, on 'Concord' grapes, were also reported by McCaskill and Morris (38) and by Morris et al. (45). Increasing the yield as a result of treatment with Daminozide was also demonstrated on apple trees by Green and Lord (23).

Joshi (31) found that the application of CCC and SADH on pimiento peppers at the 2-leaf stage increased the yield over that of untreated plants. A foliar application of 10^{-2}M CCC at the 2-leaf stage gave the highest early yield among several treatments he compared.

Tiessen (70) found that foliar applications of CCC increased the total yield of peppers started at the warmer (64-68°F) temperature.

At the cooler temperature (55-56°F), however, yield was not affected by the CCC treatment.

Read and Fieldhouse (49) reported that foliar sprays of CCC and Alar on tomato plants, at the seedling stage, resulted in increase of both early and total yields. The yield increases are attributed to a combination of effects including resistance to water and heat stress, more flowers per cluster and thus more fruits per plant. Increased yield due to a greater number of fruits per plant at high rates of Daminozide was also reported by Pisarczyk and Splittstoessor (48). Knavel (33) reported increase in number and weight of early fruit from tomatoes treated with Alar at 2500 ppm at the 3-leaf stage.

Chlorophyll Content

Leaves of many species of plants have been reported to develop a darker green color when treated with growth retardants (11,12,31,33, 52,70).

Cathey (12) found that foliar and drench applications of growth retardants, enhanced the green color of the foliage. The color intensity was directly related to the action of the growth retardant and not to mineral nutrition.

In tomato plants, darker green-color enhancement resulted from treatment with SADH (11) and from treatment with CCC (52). Tiessen (70) found that drench application to tomatoes and peppers of 10^{-3} and 10^{-4}M solutions of CCC produced darker-green plants with reduced foliage spread. Wittwer and Tolbert (85) reported that tomato plants treated with aqueous solutions of CCC and (allyl) trimethylammonium bromide (AMAB) at concentrations from 10^{-3} to 10^{-7}M had a darker-green color than untreated plants. They observed that all the known types of tomato cultivars such as dwarf, determinate, indeterminate, greenhouse forcing, early market, and processing types all responded with a more compact growth habit and deepening of green color from retardant treatments.

Nutrient Uptake

The effects that growth retardants have on mineral nutrition appear to vary among plant species (55). Knavel (33) reported that tomato transplants sprayed with CCC contained more N, P, Ca, and Mg, but less K than untreated plants. Transplants treated with Daminozide at the 3-true leaf stage contained more N and P and less Ca than untreated plants, and there was no effect on the Mg level. In another test, on tomato, Knavel (32) found an increase in Ca but a decrease in N concentration.

Adedipe (3) in 1969, demonstrated that CCC and Alar increased the N and P content in pea vines. He found also that the Mg content increased in plants treated with CCC. Both chemicals were found to decrease K. Wieneke et al. (79) reported a decrease in Ca uptake by pea and bean plants treated with SADH.

When young chrysanthemum plants were treated with Daminozide at 5000 ppm, the contents of K, B, and Si were increased in the leaves while the content of Ca and Mg were decreased (17).

Arumugan and Rao (4) showed that grapevines sprayed with Daminozide at 2,000 ppm, CCC at 2,000 ppm, and phosphon-D at 500 ppm contained more P and Ca, but less K than untreated plants.

In apple trees, Southwick et al. (66) found no appreciable influence of Alar on the foliar level of N, P, K, Ca, Mg, Mn, Zn and B, while Ashby and Looney (6) and Himelrick et al. (26) reported that the N, P, and K levels were all reduced.

According to Ashby and Looney (6), Singh demonstrated a significant reduction in leaf content of Ca, Mg and N following application of Alar as a foliar spray or a root application to one-year old apple trees. Bukovac et al. (10) reported that leaves of 'Concord' grape plants treated with Alar had reduced level of K and increased levels of Ca, Mn, Cu, and B.

Resistance to Chemical and Physical Stress

Growth retardants have been found to increase the drought resistance of some plants. The mechanisms by which they accomplish this resistance in plants is unknown.

Van Emden and Cockshull (76) found that soil application of CCC to Brussels sprouts resulted in a reduction in the number of stomata per unit area. This reduction could decrease the rate of transpiration and contribute to the plant's drought resistance as suggested by them. An increase in leaf thickness as a result of application of CCC could also contribute to drought resistance.

When Mishra and Pradhan (42) and Pisarczyk and Splittstoesser (47), treated tomato plants with Daminozide and Chlormequat, they found a reduction in the number of open stomata and thus a reduced rate of transpiration. Knavel (33) showed that tomato plants treated with Alar and CCC were more drought resistant than control plants.

Halvey and Kessler (24) found that bean plants treated with phosphon and CCC were less susceptible to water stress than untreated plants.

Growth retardants were found also to increase tolerance of some plants to high concentrations of salts (12,77). Young bean plants treated with CCC were able to withstand an application of commercial fertilizer (5-10-5) to the surface of the soil that killed untreated plants. Chauhan and Verman (15) increased the tolerance of cotton to high soil salt concentrations and drought by treatment with CCC.

III. Mode of Action of Growth Retardants

Cell Division and Enlargement

It has been reported by several authors that the sub-apical meristem is the site of activity of plant growth retardants. In this site cell division and enlargement are inhibited (12,39,59,71).

McConnell and Struckmeyer (39) reported that Alar at concentrations of 500 ppm and over to zinnia plants inhibited cell division and enlargement, resulting in multinucleate cells with abnormal nuclei.

Sachs et al. (59) presented a histological basis for understanding the action of growth retardants. They found that treatment of *Chrysanthemum morifolium* with Amo-1618 retarded stem elongation by preventing cell division in the sub-apical meristematic zone.

Zeevaart (89) suggested that the suppression of flowering by massive dosages of growth retardants in Pharbitis nil chois was the result of inhibition of cell division in the plumule during the period when the floral stimulus was present, thus preventing the expression of the stimulus in flower primordia.

Relation of Phytochrome

Cathey (12) reported no direct interaction between growth retardant and phytochrome the red-far-red, photoreversible system.

It was reported by Cathey (12,13), and by Wittwer and Tolbert (86) that the germination of light-promoted seeds of lettuce and Lepidium Virginicum L. was retarded depending upon concentrations. Phosphon, Amo-1618, and CCC in no way altered the dormancy of nonpromoted seeds held in darkness. All seeds held seven to ten days were beginning to germinate even at the highest concentration tested. Growth retardant substances apparently in no way entered into the initiation process of germination but were operative only when growth was started by light or gibberellin.

The competitive effects of growth-retarding chemical, light, and gibberellin on stem elongation were not direct but could be separated as shown with dark-grown Red kidney beans by Downs and Cathey (21). The retarding effect of Amo-1618 on internode growth of dark-grown beans was similar to the effect produced by brief exposures to red radiant energy. The action of Amo-1618 operated independently of the photoreaction since the retardation induced by Amo-1618 was equally great on irradiated and nonirradiated plants.

Wittwer and Tolbert (86) reported that, on many vegetative plants, treatment with growth retardants duplicated effects of a short photoperiod combined with a high light intensity.

Cathey et al. (14) reported that B-995 applied as a foliar spray controlled internode elongation of China aster, marigold, petunia, salvia, and zinnia on any daylength, without delaying flowering appreciably.

Relation to Auxin

Wittwer and Tolbert (86), and Kuraishi and Muir (34) demonstrated that CCC suppressed the growth of Avena coleoptile sections both in the presence or in the absence of indole-3-acetic acid (IAA). Gibberellin had little effect on the inhibitory action of CCC on Avena sections. Kurashi and Muir (34) suggested that the retardation of growth of pea stem by CCC was due to the lack of IAA and was independent of gibberellin. Wittwer and Tolbert (86) observed no direct effect of CCC on the growth of tomato ovaries. When 10^{-3}M IAA, 10^{-3}M gibberellin, and 10^{-4}M CCC were combined, a synergistic growth rate was induced beyond that which could be attributed to an IAA-gibberellin interaction.

Moore (44) found that 1 ug of IAA counteracted the effect of 10^{-3}M CCC added to the root medium of light-grown cucumber seedlings, but it did not nullify the action of either Amo-1618 or B-995.

Williams (81), and Williams and Stahly (82) treated apple trees with SADH and found that SADH controlled growth by inhibiting the production, movement and/or utilization of IAA.

Reed et al. (53) reported that the inhibition of shoot elongation in peas by B-995 was correlated with the inhibition of the IAA biosynthesis pathway.

Relation to Gibberellin

The action of gibberellin and growth retardants in altering the growth of plants is mutually antagonistic. This antagonism has been found for stem growth of chrysanthemum (60), wheat (71,72,85), caulescent plants (59), and cucumber seedlings (44), root tips of peas (87), and flowering of tomato (85), Samolus (8), and pharbitis (89).

Dennis et al. (20) reported that the production of (-) - Kaurene, a probable intermediate in the biosynthesis of gibberellin, in a flowering plant system is inhibited in the presence of growth retardants which resulted in an inhibition of gibberellin synthesis. According to Cathey (12), Ninneman and Lang suggested also that the action of growth retardants in plants is caused by their inhibitory effect on the biosynthesis of endogenous gibberellins.

Zeevaart (89) attempted to explain the action of growth retardants in promoting flower initiation in the short-day plant, *Pharbitis nil chois.* He found that under long-day conditions, CCC, a growth retardant which apparently inhibits gibberellin synthesis, promoted flower initiation, whereas under short-day conditions it inhibited flower initiation. He suggested that there was a maximum level of gibberellin above which floral initiation could not occur. This was exceeded under long-day and not achieved under short-day conditions. CCC lowers the gibberellin level to the proper range under long days and depressed the level below optimal under short days.

Babbit et al. (7) found that the rate of normal sequence of changes during ripening were accelerated by ethephon and SADH and delayed by gibberellin and IAA.

Lockhart reported that the growth retardants act as antigibberellins in a biological sense (35), and on the basis of his kinetic studies, in a biochemical sense (36).

According to Lockhart, growth retardants exert their influence by reducing the activity of gibberellin in the growth system. He proposed that they should be considered as antimetabolites rather than as antigibberellins or antiauxins.

IV. Effect of Mechanical Topping on Pimiento Pepper

Effect on Growth

At present, most of the pimiento acreage is established with transplants. The open-field method of growing pimiento transplants has some advantages; however, in some years unfavorable weather conditions in area of production delay the transplanting operation. The transplants become so large that they are difficult to plant with mechanical transplanters. A more effective method for holding plants within an acceptable size range is needed to facilitate mechanical harvesting and packing for shipment without further sorting. Growers have expressed an interest in removing the top one-third of oversize pimiento transplants to facilitate the transplanting operation (18).

Jaworski and Webb (27), and Jaworski et al. (29) showed that clipping of tomato transplants improved size uniformity and permitted field-holding of marketable size transplants for periods of up to two weeks. Williamson and Jaworski (83) found that clipping increased the number of marketable transplants of tomato.

Effect on Yield

Dempsey (18) found that oversize pimiento transplants topped to 12 or 16 inches in height produced higher yields of marketable red ripe fruits than transplants not topped or topped to 8 inches in height. Jaworski and Webb (28) demonstrated that pepper plants clipped 12 days prior to transplant harvest produced significantly higher yields than nonclipped plants. Clipped pepper transplants were smaller than nonclipped plants of the same age. Knavel (32) reported that clipped pepper transplants produced as well as control plants but N content decreased and Ca content increased from clipping. Pisarczyk and Splittstoesser (47) reported that clipped tomato plants were delayed in fruit set one month, but the total seasonal yield was unaffected.

Effect on Branching

Knavel (32) found that clipped pepper transplants increased branching and fruiting sites. Rylski and Halvey (58) reported that retarding apical development of the pepper plants by pinching stimulated the lateral buds on the main stem to sprout and caused the plant to branch out, bushlike.

CHAPTER III

METHODS AND MATERIALS

This study consisted of both greenhouse and field experiments. Greenhouse studies were conducted during spring and fall of 1979 at the Plant and Soil Science greenhouse in Knoxville. Field studies were conducted during summer of 1979 at the Plant and Soil Science Field Laboratory near Knoxville.

I. General Procedure

Greenhouse Studies

A factorial combination of treatments of chemicals (Daminozide and CCC), concentrations, and time of application was utilized for greenhouse experiments (Table 2). A 2x4x7 factorial arrangement of treatments in a randomized complete block design with 3 replications was utilized.

Fifty seeds of pimiento peppers (*Capsicum annuum* var. Truhart Perfection) were soaked in chemicals for 24 hours immediately prior to planting. Seeds were soaked in Petri dishes. After soaking, both treated and nontreated seeds (50 seeds each) were planted in 21.5 cm azalea pots containing a recommended soil mixture and placed in the greenhouse. The pots were watered as needed and starter fertilizers were used.

Solutions of appropriate concentrations were prepared immediately prior to application. Tween-20 at 0.5 percent volume/volume was added as a surfactant. Daminozide and CCC were applied at concentrations of

Table 2. Names, Concentrations, and Times of Application of Growth Retardant Treatments.

Factors	Treatment Components
Chemicals	Daminozide[1], CCC[2]
Concentrations	$5x10^{-2}M$, $10^{-2}M$, $5x10^{-3}M$, $10^{-3}M$
Times of application	Seed application[3], 2-leaf, 4-leaf, seed + 2-leaf, seed + 4-leaf, seed + 2-leaf + 4-leaf, 2-leaf + 4-leaf

1. In the literature review may also be referred to as SADH, B-9, B-995, B-Nine, or Alar.

2. In the literature review may also be referred to as Cycocel or Chlormequat.

3. In data presentation is abbreviated as follows: Seed = S, 2-leaf = 2-L and 4-leaf = 4-L.

$5x10^{-2}M$, $1x10^{-2}M$, $5x10^{-3}M$, and $1x10^{-3}M$ as a seed soak and as foliar sprays at 2 and 4-leaf stage and at all combinations of concentrations and stages. The first foliar spray was applied after the appearance of the first two true leaves. The second spray was applied at the 4-leaf stage. The foliar sprays were applied to the point of run-off using a portable hand sprayer.

After chemical treatment and when plants were ready to transplant (about 47 days), plants were transplanted into individual pots of 15.2 cm using a recommended soil mixture and were grown under greenhouse conditions. Insecticides were used as needed.

Field Studies

Field studies consisted of chemical and topping experiments. Plants used for these studies were treated and seed germinated under greenhouse conditions.

Chemical experiment. Seed germination and chemical treatments for this experiment were similar to those described for the greenhouse studies. Selected treatments (i.e.; 31) from the combination of treatments utilized in the greenhouse plus a control were chosen for this experiment. After the treatments had been imposed and the plants had attained proper size (about 54 days after seeding), they were transplanted to the field. The experiment was arranged in a randomized complete block design with 3 replications.

<u>Topping experiment</u>. To attain plants of different heights, 4 seedings were made at approximately 14 day intervals from 2 February through 20 March 1979.

Seeds were planted in flats containing a recommended soil mixture and plants were grown under greenhouse conditions. Seeding dates were 3/20, 3/2, 2/16, and 2/2/1979 for control, transplant tops clipped once, twice, and three times treatments, respectively. The treatments consisted of plants topped to 22.8 cm once, twice, three-times, and nontopped control. Additional treatments in this experiment included transplants imported from Florida which were separated into size categories of: (1) small (18 cm height) (2) medium (21.5 cm height) (3) large (25 cm height), and (4) mixed. The plants for the mixed treatments consisted of a random assortment of all sizes and averaged about 22 cm in height (Figure 1). After separation into proper size categories and topping, the plants were set in the field. The experiment was arranged in a randomized complete block design with 4 replications.

For both field experiments, the individual plot size was one row 4.5 meters long consisting of 10 plants. The distance between rows was 100 cm and plants were 45 cm apart in the row. Fertilization and pest control as recommended for commercial production were followed. Fertilization consisted of a preplant broadcast application of 254.2 Kg/ha of 6-12-12 fertilizer. An additional application of 33.6 Kg/ha nitrogen as a sidedressing was made at the fruit-set stage. Trifluralon at 0.84 Kg/ha was applied preplant for weed control. Supplemental irrigation was provided whenever necessary.

Figure 1. Transplants from Florida sorted into respective size categories.

II. Data Collection

Greenhouse Experiments

Morphological measurement: At the time of transplanting, two plants from each treatment were randomly selected for root length measurements after roots were separated from the soil by soaking them briefly in water and length of longest root was recorded. Measurements were made to the nearest millimeter. Plant height was measured from the pot soil surface to apical bud region at transplanting and again 75 days after transplanting. Stem length was recorded at the same times by measuring the length of stem from the pot soil surface to the first primary region.

Stem diameter measurements were made with a caliper at the basal and the apical regions about 95 days after transplanting. Base diameter was recorded between the first and second internodes and top diameter was recorded at the highest internode on the stem.

The number of days from planting until the appearance of the first inflorescence was recorded for each plant of each treatment.

Yield measurements: The number of fruits was recorded at two harvests. In the first harvest, only the ripe fruits were harvested and recorded. In the second harvest all fruits were harvested and the total number was separated into ripe, breaker, and green fruits. Ripes were completely red, breakers were about 50% red, and the others with no red color development were considered as green. Data were added together to give total number of fruits.

Fruits were weighed to nearest 0.1 gm. Fruit weights from both harvests were added together to give total yield.

Nutrient analysis: Plant tissue samples for nutrient analyses were taken at transplanting (47 days) and at 95 days after transplanting. Random samples were taken from leaves and petioles of plant of each treatment. Samples were oven dried for 48 hr at 75°C. The samples were ground to pass through a 20 mesh screen and were stored until analyzed.

Nitrogen analysis was done on the Technicon autoanalyzer from 0.2 gm sample by a total nitrogen (NH^{+}_{4}) procedure (69) while the phosphorus, potassium, magnesium, and calcium analyses were done on the autoanalyzer from a 0.5 gm sample after a wet digestion procedure (9). Data are expressed on a percentage of dry weight basis.

Field Experiments

Data collected from the field experiments consisted of plant stand (number of plants surviving), total yield and number of ripe fruits, yield and number of ripe fruit in first three harvests, and yield and number of all fruits in last harvest. The number of secondary branches also was obtained in the plant topping experiment only. Harvesting was done 82, 92, 104, and 118 days after transplanting.

III. Statistical Analysis

Analysis of variance was performed on all data and means were separated by Duncan's multiple range or by orthogonal contrast tests where appropriate (65). All statistical analyses were performed by The University of Tennessee Computer Center and Statistical Analysis System (SAS). An arcsin transformation was made on all data involving plant nutrient content.

CHAPTER IV

RESULTS AND DISCUSSION

Because of the large number of treatments in the greenhouse and field studies, 56 and 32, respectively, and kinds of data taken in these experiments, not all results from each individual treatment are presented and discussed. For the most part, only results from those treatments and/or treatment combinations of particular biological interest and statistical significance are presented and discussed.

I. Greenhouse Experiments

Plants treated with growth retardants showed more extensive development of root systems than untreated plants. Plants treated with CCC had larger root systems than those treated with Daminozide (Figures 2, 3). As a result of treatment with growth retardants, internodal elongation in the subapical region was decreased. The treated plants appeared about half the size of untreated plants (Figures 4, 5).

The interaction effects of growth retardants, concentration, time of application, and the season on root length and stem height were significant (Table 22, Appendix). Because of the biological importance of these interactions, we considered to the interaction effect of growth retardants and concentration separately for each season in each individual stage of application.

Figure 2. Effect of CCC on the development of root system.

Figure 3. Effect of Daminozide on the development of root system.

Figure 4. Retardation of growth from an application of Daminozide. Note shortening of the internode.

Figure 5. Retardation of growth from an application of CCC.

Roots of plants grown in the spring and treated with both retardants at the seed stage responded differently than those of plants grown in the fall (Figure 6). As the concentration of both retardants was increased from 10^{-3} to 5 x 10^{-3}M, root length of plants grown in the fall increased while the reverse occurred on those grown in the spring. With the exception of Daminozide treated plants in the fall, further increases in the concentration to 10^{-2}M resulted in increased root length of plants receiving both retardants and grown in both seasons. For most treatments, further increases in concentration to 5 x 10^{-2}M had the reverse effect on root length.

Root length was influenced by growth retardants and the response varied among times and concentrations applied. To illustrate these effects, results from selected stages of application are presented. Plants grown in the spring and treated with Daminozide at the 4-leaf stage at concentrations of 10^{-3} and 5 x 10^{-3}M had longer roots than those treated with CCC at identical concentrations (Figure 7). Root length of plants treated with both retardants was increased when the concentration was increased from 10^{-3} to 5 x 10^{-3}M.

In the fall, at seed + 4-leaf and 2-leaf + 4-leaf stages CCC resulted in a decrease on root length when the concentration was increased from either 10^{-3} to 5 x 10^{-3}M or from 10^{-2} to 5 x 10^{-2}M (Figures 8 and 9). On the other hand, at the stages mentioned above the longest roots were found on plants receiving 10^{-2}M CCC. With both stages mentioned above in the fall, reverse results were found with Daminozide treated plants. An increase in root length of plants

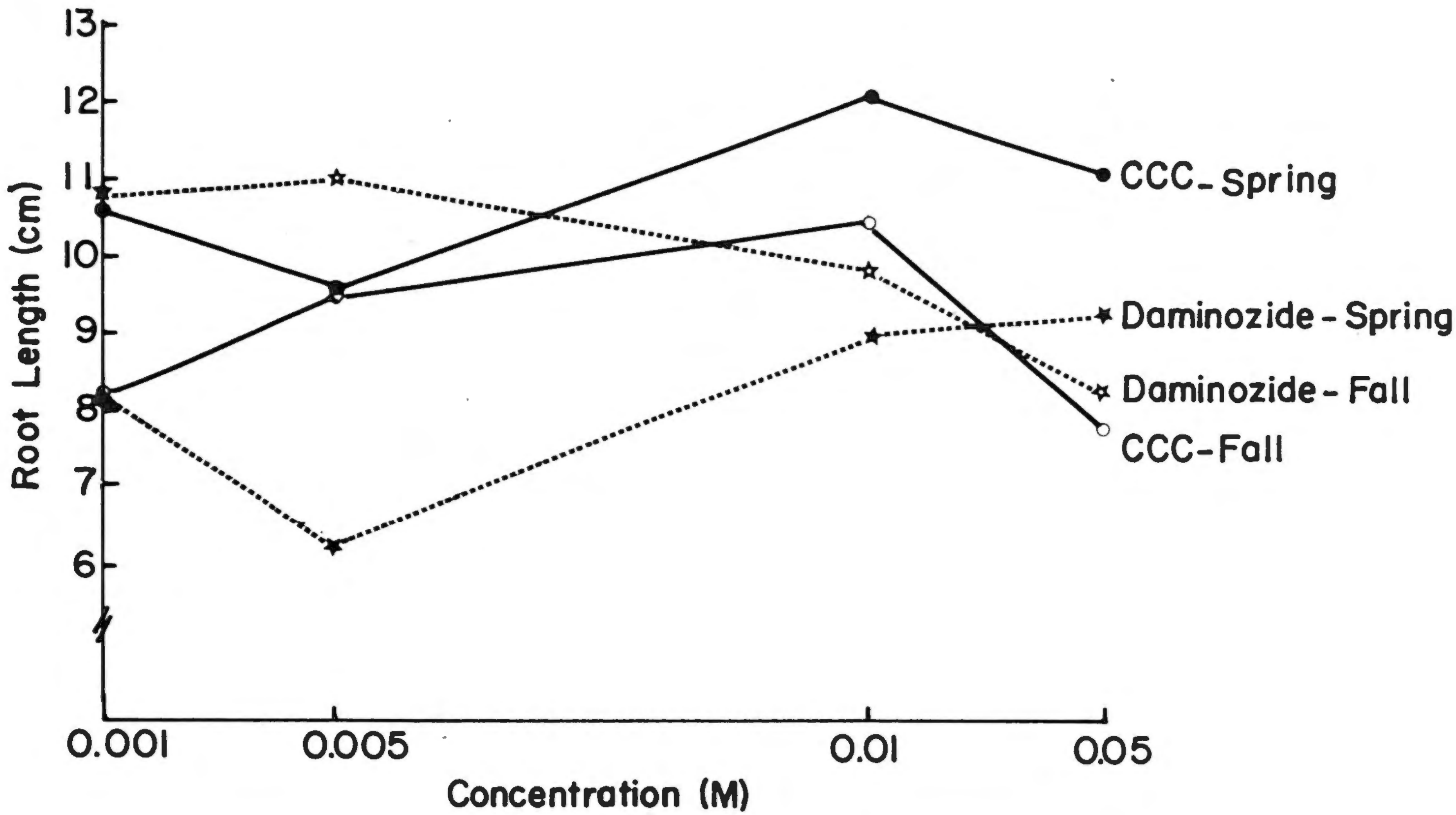


Figure 6. Interactive effect of growth retardant, concentration, time of application (seed application), and season on root length of Pimiento Peppers. Data for concentration is plotted semilogarithmically, 2 cycle.

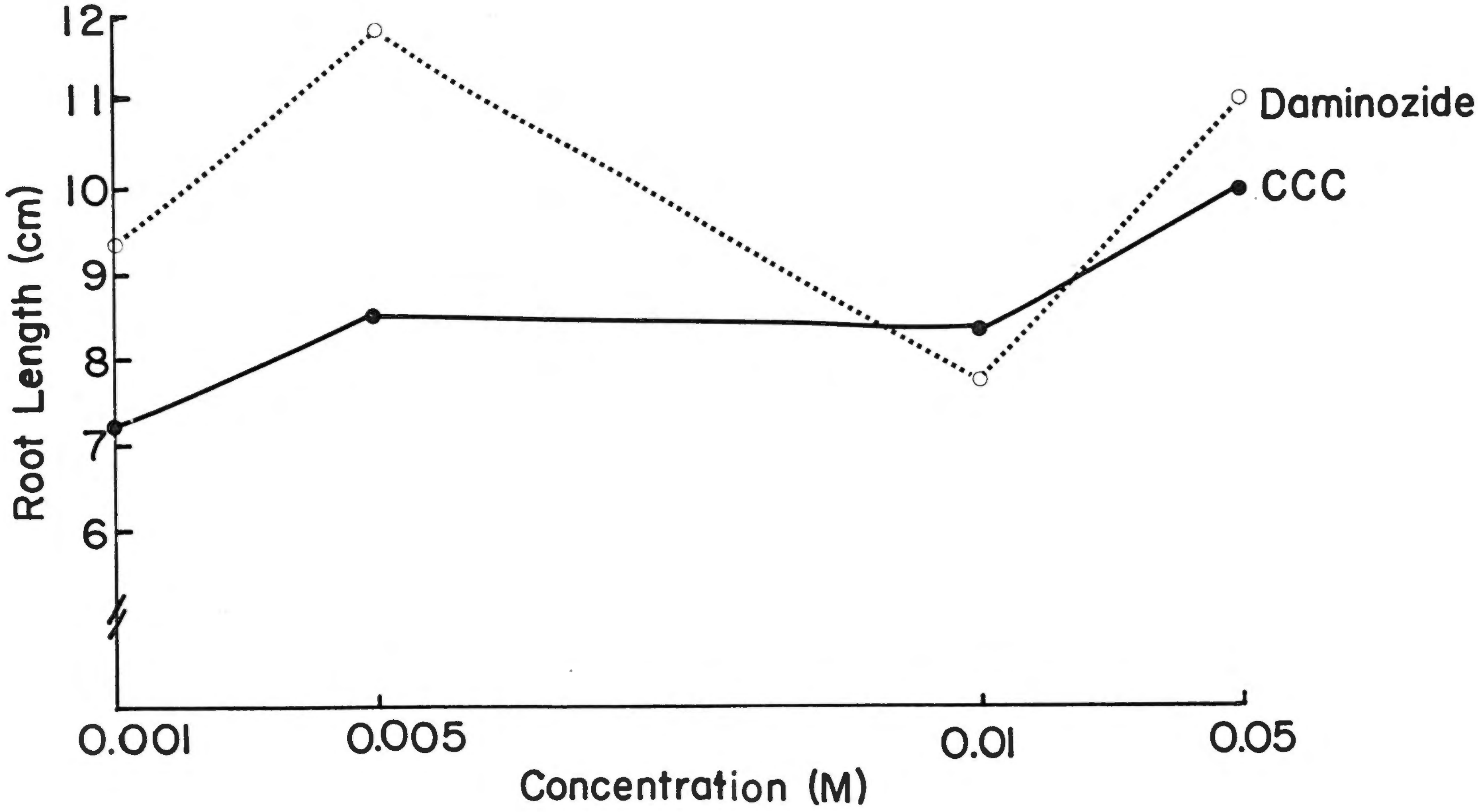


Figure 7. Interactive effect of growth retardant, concentration, time of application (4-leaf stage), and season (Spring) on root length of Pimiento Peppers. Data for concentration is plotted semilogarithmically, 2 cycle.

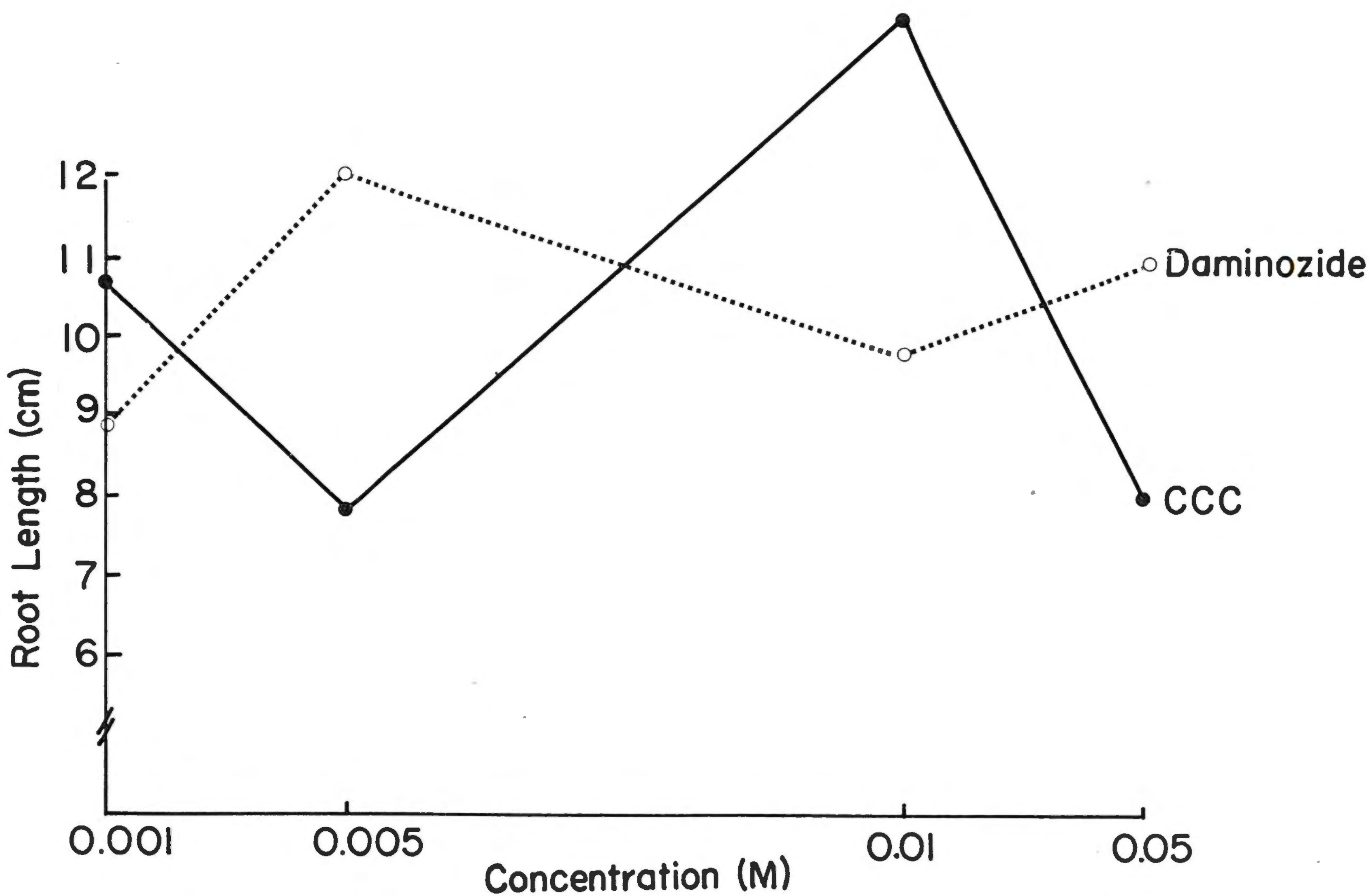


Figure 8. Interactive effect of growth retardant, concentration, time of application (Seed + 4-leaf stage), and season (Fall) on root length of Pimiento Peppers. Data for concentration is plotted semilogarithmically, 2 cycle.

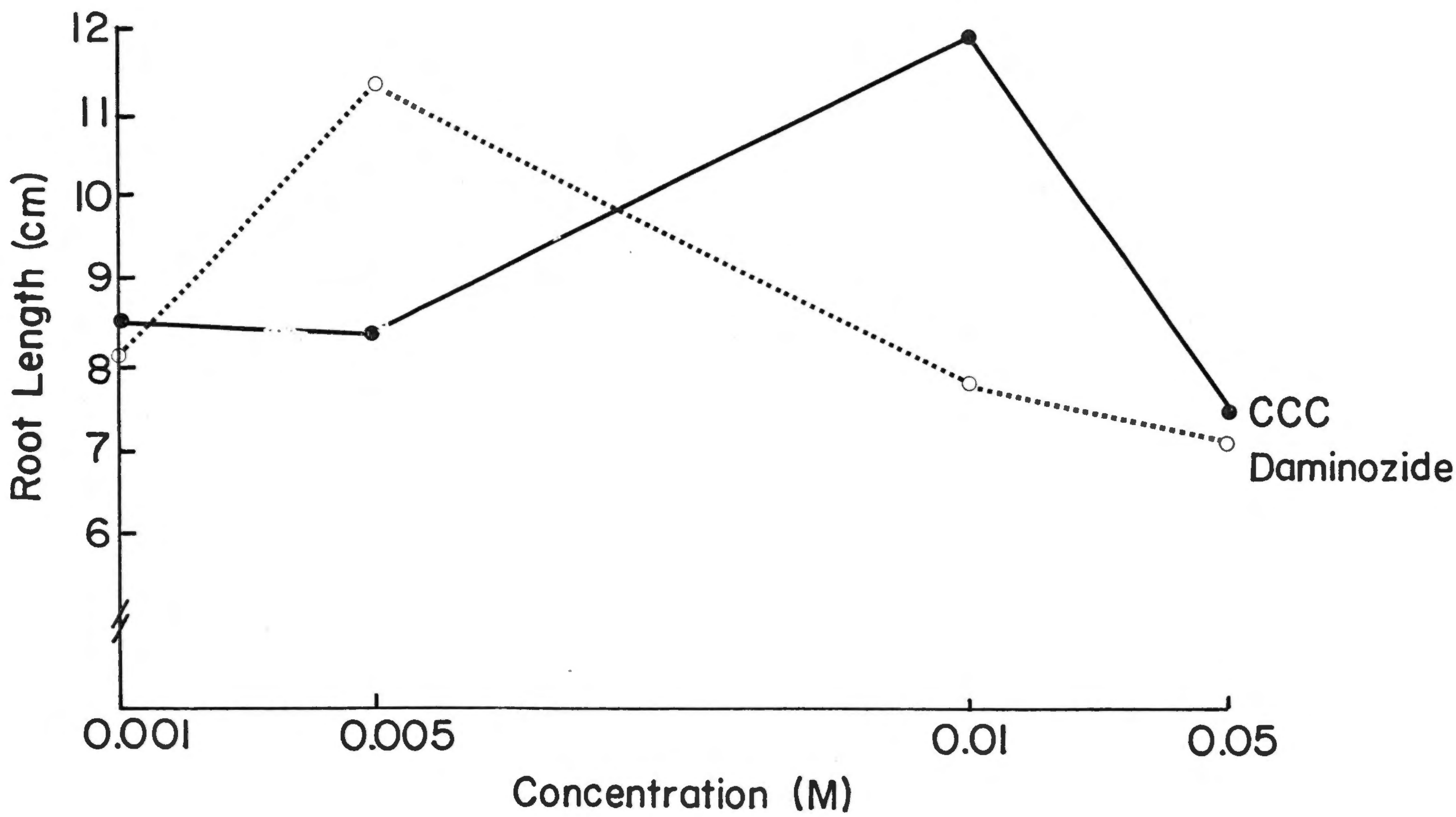


Figure 9. Interactive effect of growth retardant, concentration, time of application (2-leaf + 4-leaf stage), and season (Fall) on root length of Pimiento Peppers. Data for concentration is plotted semilogarithmically, 2 cycle.

treated with Daminozide at both stages in the fall was found when the concentration increased from 10^{-3} to 5×10^{-3}M. Further increase in concentration had either reverse or no effect in this response.

At seed application in the spring, plants treated with both retardants resulted in a decrease in stem height as the concentration was increased from 10^{-3} to 5×10^{-3}M (Figure 10) while further increases in concentration to 5×10^{-2}M resulted in a slight increase in stem height. At the same stage in the fall, both retardants had little or no effect at concentration up to 10^{-2}M. Daminozide tended to reduce stem height in the fall at a concentration of 5×10^{-2}M. Overall stem height of plants was greater in fall than in spring. At seed + 2-leaf stage of application, more reduction in stem height was obtained in the plants growing in the fall and treated with both retardants than those growing in the spring, but ultimately plants growing in the spring season were shorter than those growing in the fall (Figure 11). Stem height of plants treated with both retardants in both seasons decreased as the concentration increased from 10^{-3} to 5×10^{-2}M. Similar results were obtained from plants treated at 2-leaf + 4-leaf stage in the spring with both retardants (Figure 12). Stem height was decreased from 22.0 to 15.7 cm and from 20.1 to 13.1 cm with CCC and Daminozide treatments, respectively, as the concentration was increased from 10^{-3} to 5×10^{-3}M.

The interactive effect of season and concentration on stem height is illustrated in Figure 13. Stem height was reduced from about 29.1 to 23.3 cm and from 22.2 to 19.0 cm in the fall and in the spring,

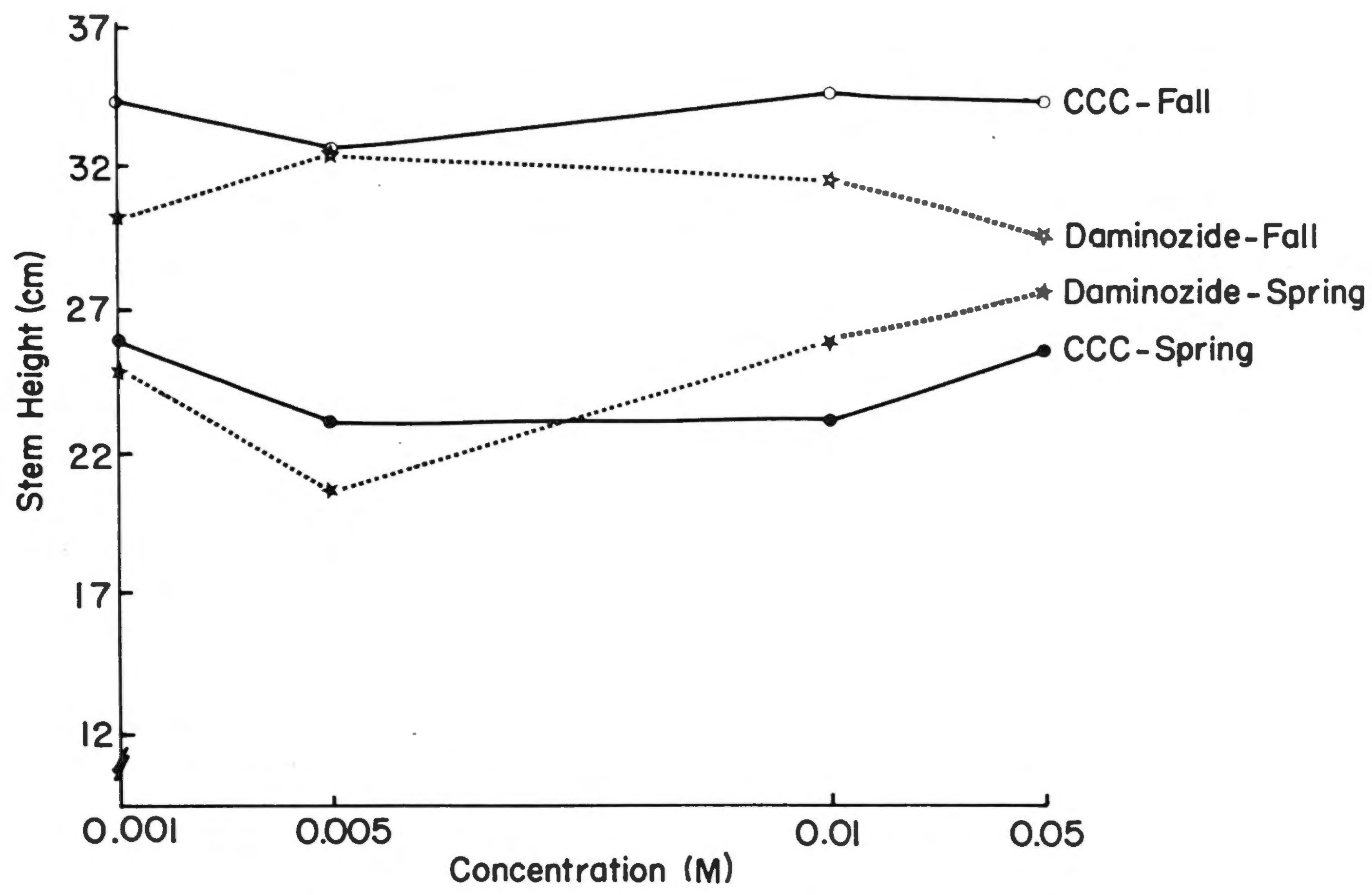


Figure 10. Interactive effect of growth retardant, concentration, time of application (seed application), and season on stem height of Pimiento Peppers. Data for concentration is plotted semilogarithmically, 2 cycle.

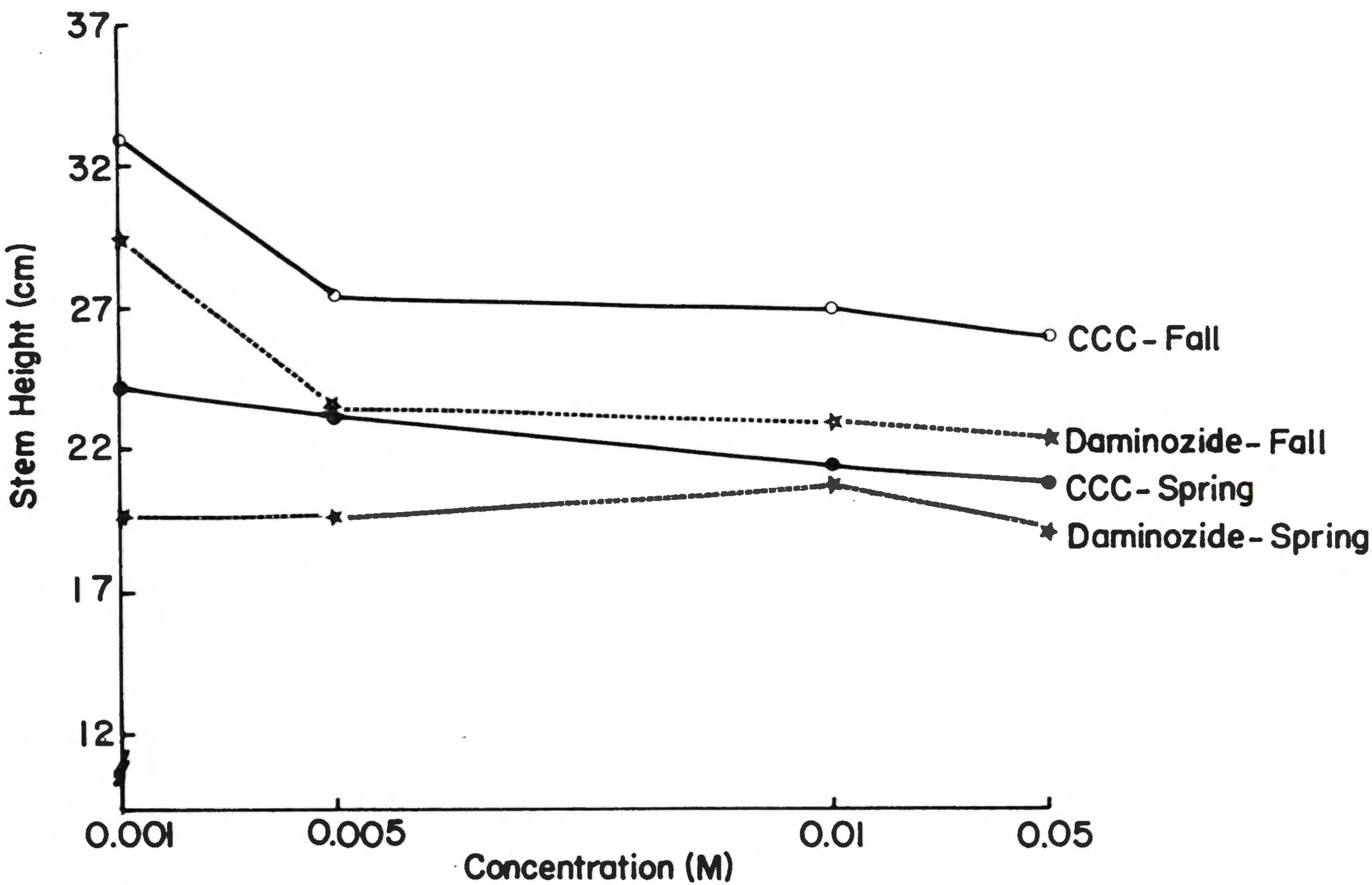


Figure 11. Interactive effect of growth retardant, concentration, time of application (seed + 2-leaf stage) and season on stem height of Pimiento Peppers. Data for concentration is plotted semilogarithmically, 2 cycle.

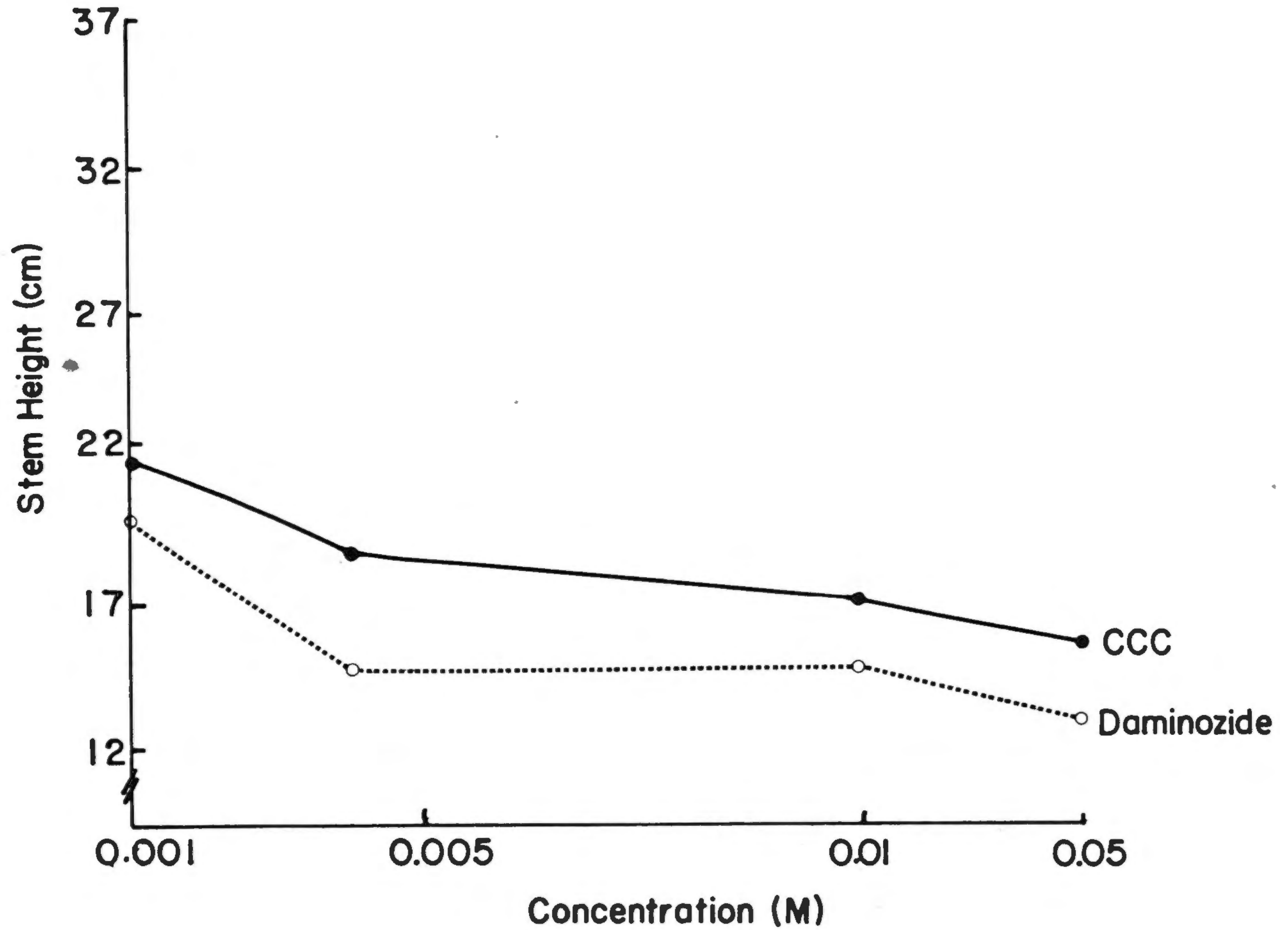


Figure 12. Interactive effect of growth retardant, concentration, time of application (2-leaf + 4-leaf stage), and season (Spring) on stem height of Pimiento Peppers. Data for concentration is plotted semilogarithmically, 2 cycle.

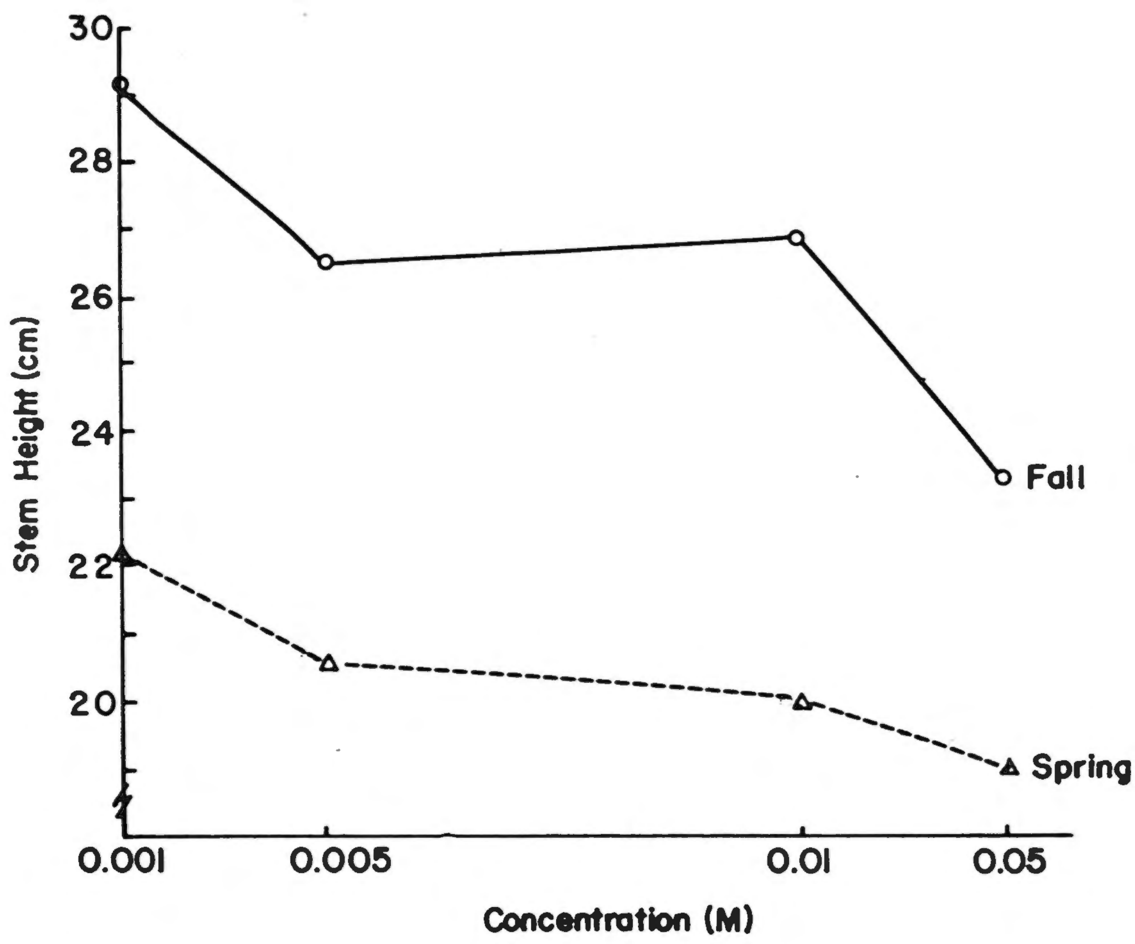


Figure 13. Interactive effect of season and concentration (semilogarithmic, 2 cycle) on stem height of Pimiento Peppers.

respectively, as the concentration was increased from 10^{-3} to 5×10^{-2}M. Plants treated with growth retardants responded more in the fall than in the spring but ultimately plants growing in the spring season were shorter than those in the fall. This was true because the environmental factors of light and temperature in the fall were more conducive to vegetative growth even though chemicals had an effect. In general, CCC and Daminozide at all concentrations and stages of application were effective in increasing root length and retarding stem height of pimiento.

The action of these growth retardants on stem height was specific on internodal elongation in the subapical region since the other parts of plants were not noticeably affected (Figure 4, 5, pp. 35 and 36). Although there were considerable differences in height between treated and untreated plants at the seedling stage, treated plants resumed growth and reached about the same height as untreated plants by the end of the growing season.

Joshi (31) found an increase in root length of pimiento peppers as a result of treatment with CCC and Daminozide. Read and Hosler (50) reported similar results from CCC and B-9 on root growth of Geranium, Chrysanthemum and Dahlia plants.

A reduction in height is a typical plant response of growth retardants. Tolbert (72) reported that wheat plants treated with CCC had shorter stems. Similar results were also presented on tomato plants by Knavel (33) while working with CCC and by Pisarczyk and Splittstoesser (47,48) while working with Daminozide and Chlormequat.

Joshi (31) reported similar results with CCC and SADH at concentrations of 10^{-2}, 10^{-3}, and 10^{-4}M applied at 2, 4-6, and 6-8 leaf stages on pimiento peppers. He found that nearly all chemical concentrations were effective in retarding plant height of pimiento. Similar results were also presented by Yadava (88) while working with B-995 on tobacco plants. He reported that the effect of B-995 on tobacco plants differed according to the concentration of the solution applied. Stem length and total height of the tobacco shoots were significantly less than those of untreated plants.

Application of CCC and Daminozide appear useful in the mechanical transplanting of pimiento peppers. It is probable that application of growth retardants at the seedling stage of pimiento plants will overcome the problem of oversized transplants, which often develops during an unfavorable season. Similar benefits can be obtained with mechanical topping. In this regard it is possible that plant growth retardants may substitute for mechanical topping. Knavel (32) reported results which support the above while comparing clipping with Daminozide on bell peppers. He found that both clipping and Daminozide reduced growth. Campbell (11) found that ethephon and Daminozide improved quality and uniformity of clipped and nonclipped transplants of tomato.

Foliar applications of growth retardants at all concentrations and times of application resulted in an enhancement of green color of pimiento foliage (Figure 14). Cathey (12) found similar results and reported that color development was directly related to the action of the growth retardants and not to mineral nutrition. Plants treated with

Figure 14. Increase in stem diameter with the application of growth retardants.

growth retardants appeared to show more resistance to water stress than untreated plants. Although all the plants were watered at the same time, treated plants had thicker, more succulent leaves than untreated plants.

Application of growth retardants resulted in an increase in stem diameter (Figure 14). Although differences in actual stem diameter between chemicals within season are rather small (about 0.2 - 0.7 mm, Figures 15 and 16), the interactive effects of chemical, time of application, and season on top stem diameter were significant (Table 22, Appendix). With both retardants and all stages, stem diameter was larger in the fall than in the spring. With an exception of 2-leaf stage, plants treated with Daminozide at all times of application had larger stems than those treated with CCC in the spring experiment, while the reverse was true in the fall experiment. On the other hand, at the 2-leaf stage CCC was more effective than Daminozide in increasing stem diameter in the spring experiment while Daminozide was more effective than CCC in this response in the fall experiment. The repeated foliar application (i.e., 2-leaf + 4-leaf) was the most effective of the stages compared in increasing stem diameter with both retardants and in both seasons. Table 3 illustrates the interactive effect of growth retardants, time of application, and season on diameter of pimiento stem. In the fall, stems of both the CCC and Daminozide treated plants were significantly increased over those of the control. CCC was more effective than Daminozide. The interactive effect of growth retardant and concentration, and season and concentration on top

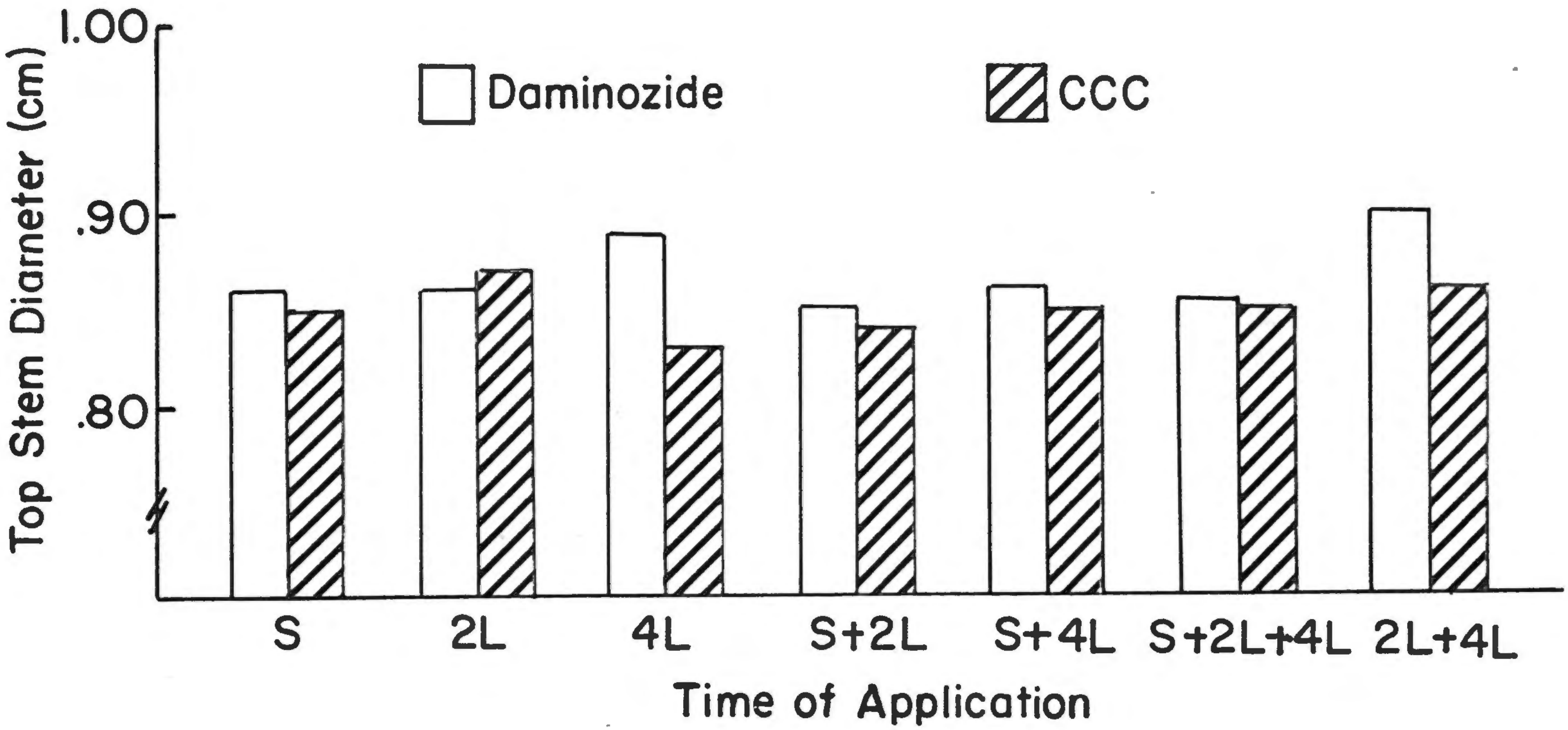


Figure 15. Interactive effect of growth retardant, time of application, and season (Spring) on top stem diameter of Pimiento Peppers.

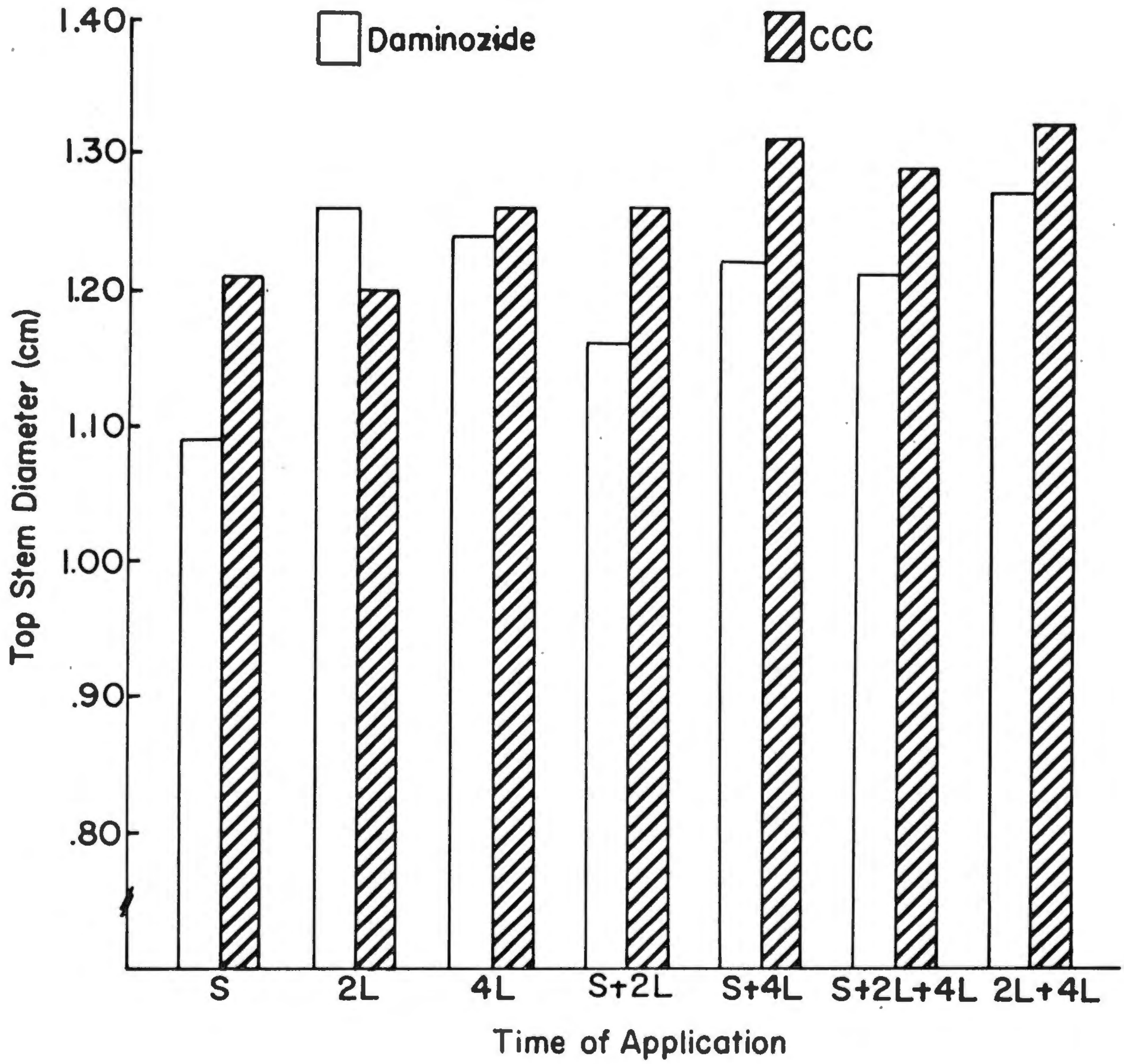


Figure 16. Interactive effect of growth retardant, time of application, and season (Fall) on top stem diameter of Pimiento Peppers.

Table 3. Interactive Effect of Growth Retardant, Time of Application and Season on Stem Diameter of Pimiento Peppers in the Greenhouse.[y]

Chemical	Top Stem Diameter (cm)
CCC	1.21a[z]
Daminozide	1.09 b
Control	1.00 c

[y]Data is for seed application from fall experiment.

[z]Mean separation within columns by Duncan's Multiple Range Test, 5% level.

stem diameter were significant (Table 22, Appendix). These interactions are illustrated in Figures 17 and 18. There was a decrease in the top stem diameter with both retardants when the concentration was increased from 10^{-3} to 5×10^{-3}M. On the other hand, an increase in concentration from 5×10^{-3}M to 5×10^{-2}M resulted in an increase in stem diameter from 1.02 to 1.08 cm and from 0.99 to 1.12 cm with CCC and Daminozide, respectively (Figure 17). The interactive effect of season and concentration on top stem diameter resulted in a thicker stem diameter in the plants grown in the fall than those grown in the spring (Figure 18). It appears that plants grown in the fall have a higher vegetative growth than those grown in the spring (Figure 13, p. 46, 18).

Several researchers also have shown an increase in stem diameter from retardant treated plants. Tiessen (70) reported an increase in stem diameter of tomato and pepper when treated with soil drenches and foliage spray of CCC. Read et al. (52) found that stem diameter was doubled in tomato plants treated with CCC. Scherff (62) found an increase in bean stems as a result of treatment with growth retardants. He suggested that this increase in stem diameter was due to the stimulation of cell production in the cambium accompanied by a delay in cell differentiation and to an increase in cell volume of the parenchymatous cortical cells. The greater increase in stem diameter of pimiento by CCC treatments found in this study was also reported by Joshi (31) while working with SADH and CCC on pimiento peppers. He demonstrated that treated plants showed an increase in the volume of parenchymatous pith cells and an increase in the number of conducting

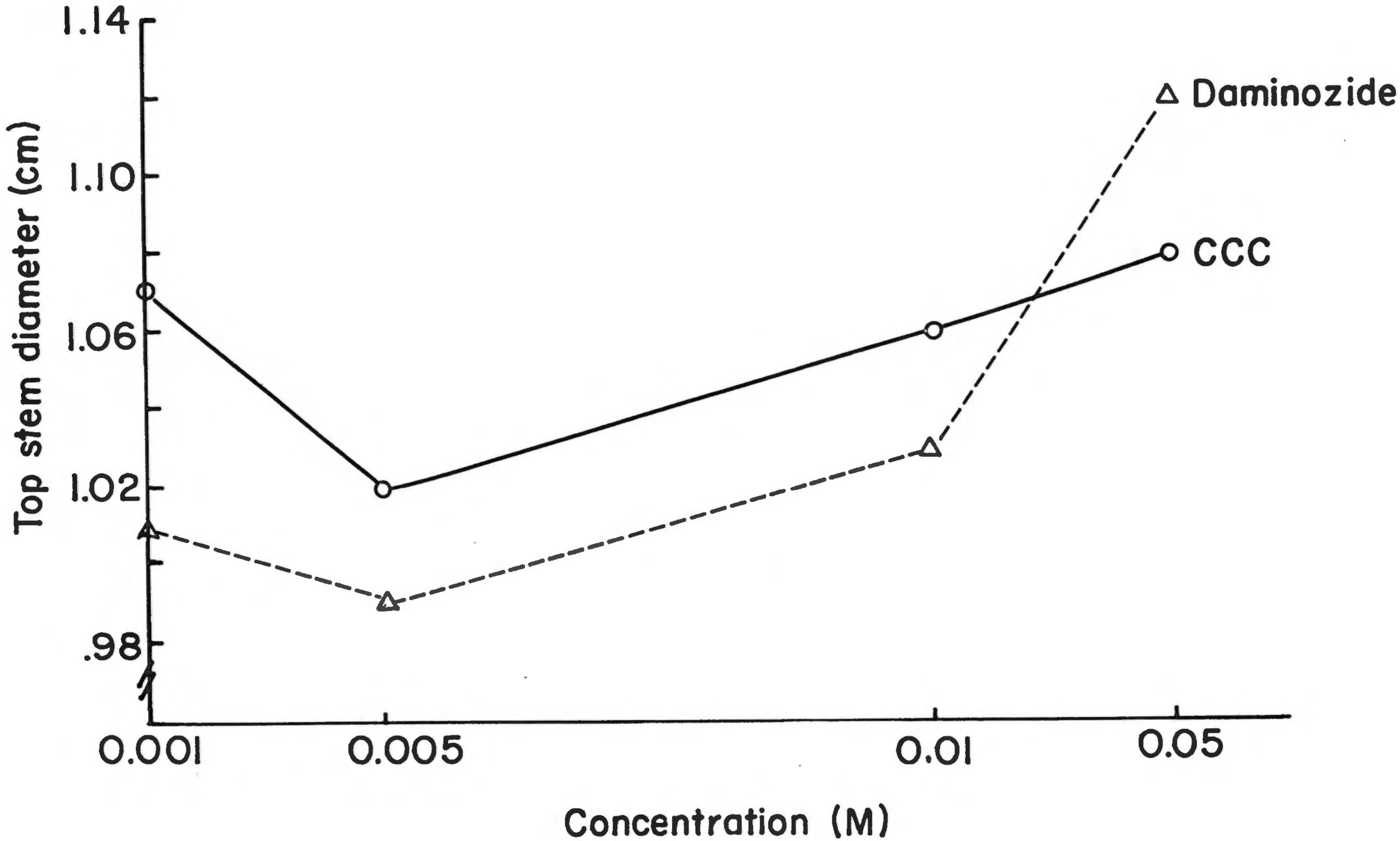


Figure 17. Interactive effect of growth retardant and concentration (semilogarithmic, 2 cycle) on top stem diameter of Pimiento Peppers.

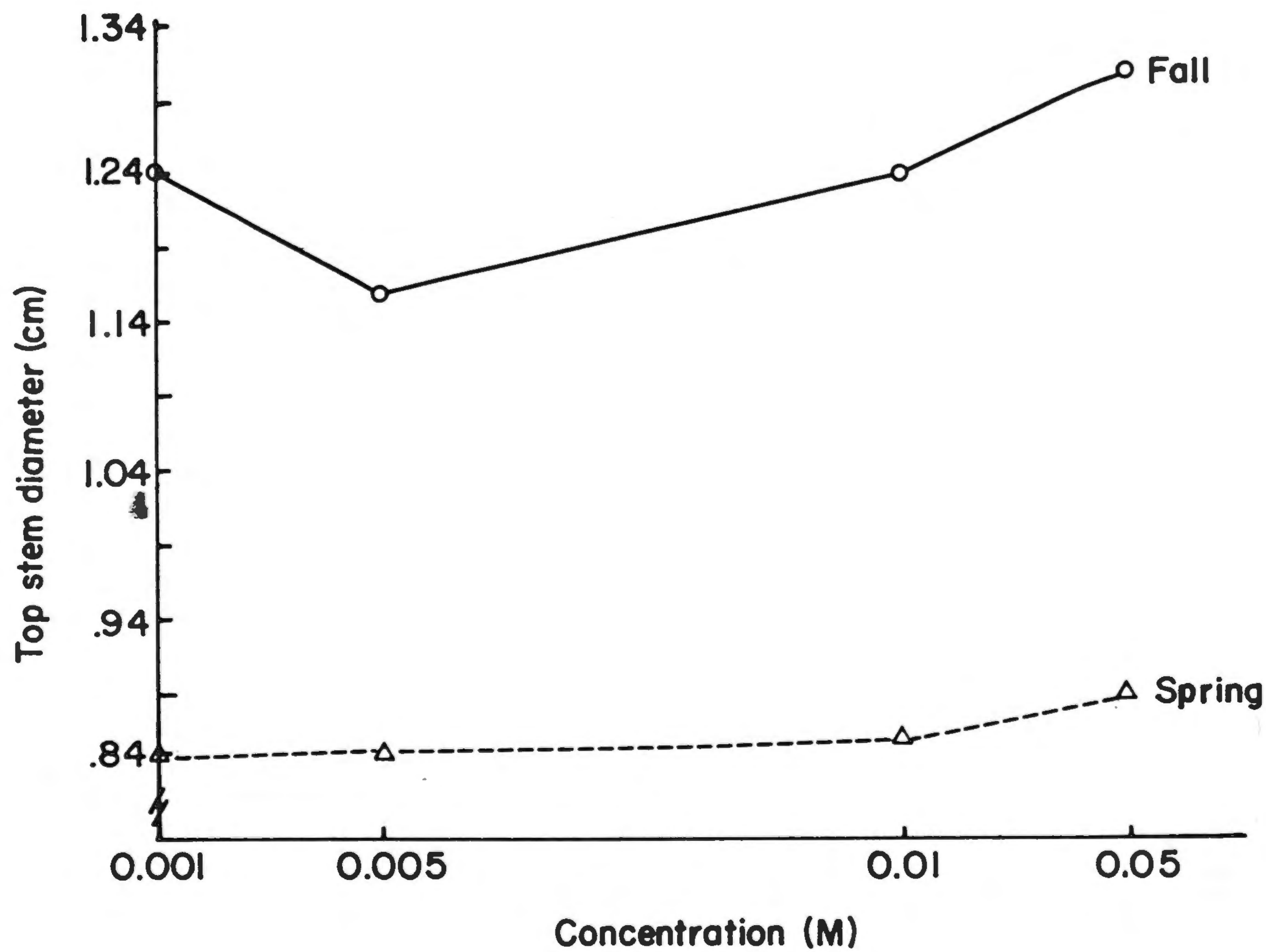


Figure 18. Interactive effect of season and concentration (semilogarithmic, 2 cycle) on top stem diameter of Pimiento Peppers.

tissues. He also found that plants treated with CCC showed about 6-7 more rows of conducting tissues than control plants.

Application of growth retardants resulted in an enhancement of flowering (Figure 19). Growth retardants apparently promote flowering by modifying the activity in the cambium. This results in an abnormal type of cells in the xylem and the disappearance of sclerenchymatous cells adjacent to the cortex. The restriction of growth presumably alters the metabolism and creates conditions conducive to flower initiation (12).

The interactive effects of chemical, time of application, and the season on flowering was significant (Table 22, Appendix). These interactions are illustrated in Figures 20 and 21. With an exception of 2-leaf and seed + 2-leaf stages, at all other stages in both seasons, CCC was more effective than Daminozide in promoting earlier flowering of pimiento. On the other hand, at 2-leaf and seed + 2-leaf stages, Daminozide was more effective than CCC in this response. The interactive effect of growth retardant, time of application, and season on flowering is shown in Table 4. At 2-leaf, seed + 2-leaf, seed + 4-leaf, and seed + 2-leaf + 4-leaf stages in the fall, both CCC and Daminozide promoted earlier flowering. CCC enhanced flowering more than Daminozide. CCC and Daminozide treated plants bloomed up to 16 and 7 days, respectively, earlier than control plants. From Figures 20 and 21 and data of Table 4, it appears that there was much difference in flowering behavior between fall and spring.

In general, the time from transplanting to flowering was much shorter in the fall than in the spring. This should be true since the

Figure 19. Enhancement of flowering with the application of growth retardants.

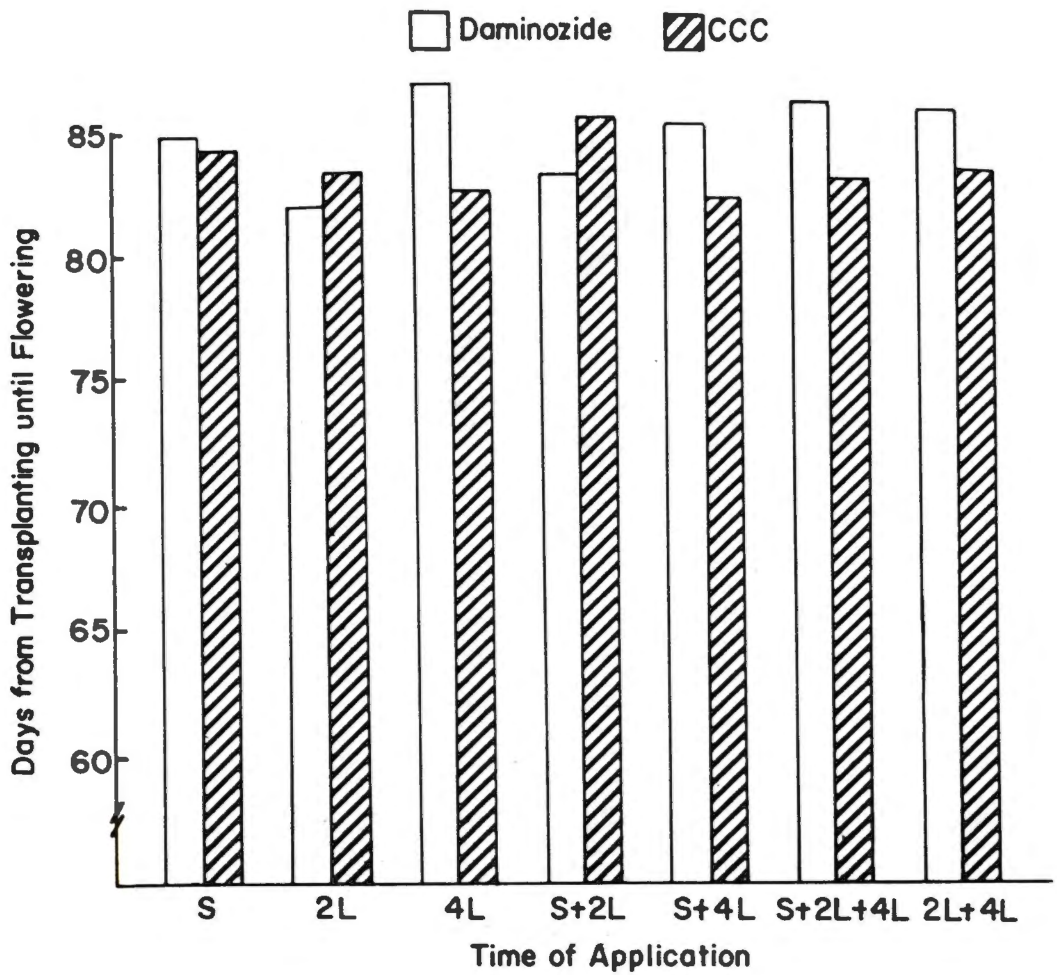


Figure 20. Interactive effect of growth retardant, time of application, and season (Spring) on time of flowering of Pimiento Peppers.

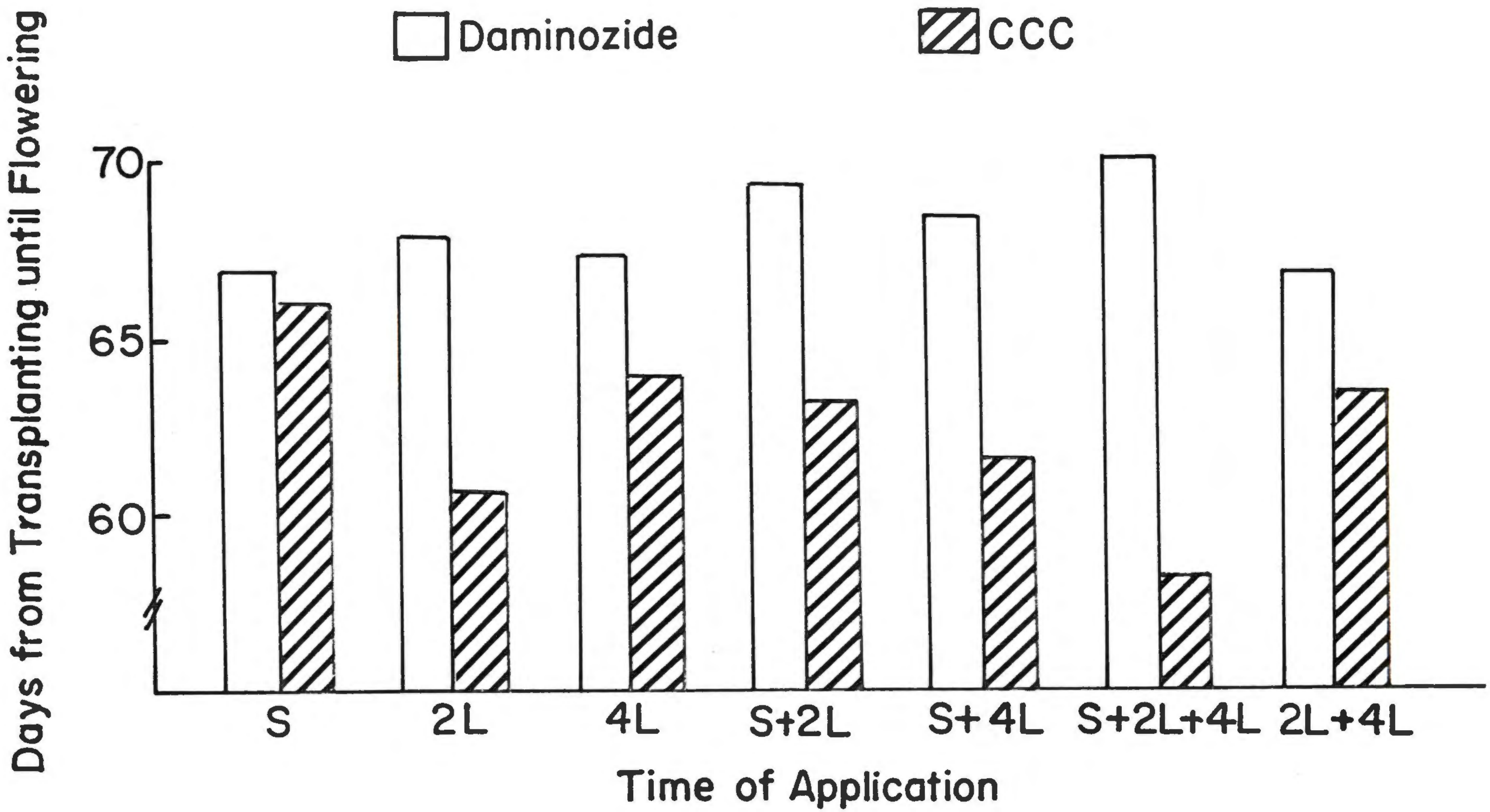


Figure 21. Interactive effect of growth retardant, time of application, and season (Fall) on time of flowering of Pimiento Peppers.

Table 4. Interactive Effect of Growth Retardant, Time of Application, and Season on Time of Flowering of Pimiento Peppers in the Greenhouse.

	Number of Days					
	Spring		Fall			
Chemical	2-L Stage	Seed + 2-L + 4-L Stage	2-L Stage	Seed + 2-L Stage	Seed + 4-L Stage	Seed + 2-L + 4-L Stage
CCC	83.3a[z]	82.9 b	60.6 c	63.3 c	61.4 c	58.3 c
Daminozide	81.8 b	86.2a	68.1 b	69.4 b	68.6 b	70.2 b
Control	76.0 c	76.0 c	76.0a	76.0a	76.0a	76.0a

[z]Mean separation within columns by Duncan's Multiple Range Test, 5% level.

environmental conditions differed considerably between the two seasons. It seems that the environmental conditions, especially the temperature, were more favorable to pimiento in the fall which might have resulted in a synergistic effect with the growth retardants. This result was true also since pimiento pepper is a warm season crop. Figure 22 illustrates the interactive effect of growth retardant and concentration on time of flowering. In general, at all concentrations, CCC was more effective than Daminozide in shortening the time from transplanting until flowering. CCC was most effective at 10^{-2}M while Daminozide was most effective at 10^{-3}M.

Joshi (31) reported similar results while working with SADH and CCC on pimiento peppers. He demonstrated that application of CCC was more effective than SADH (Daminozide) in promoting early flowering. Acceleration of flowering as a result of treatment with growth retardants was also reported on rhododendron by Stuart (67). He showed that these responses were not dependent on age, size of plant, specific photoperiod, or temperature. Several workers reported that tomato plants treated in the cotyledonary stage with CCC flower earlier and produce a larger number of flowers than untreated plants (2, 85, 86). Similar results are produced by exposure of plants to intense light and low temperature. Since the blossoms were not affected by retardants and they were typical for pimiento, it appears that the growth retardants did not inhibit or produce any morphological effect on the growing point i.e., the apical region, so their major influence was on the subapical regions.

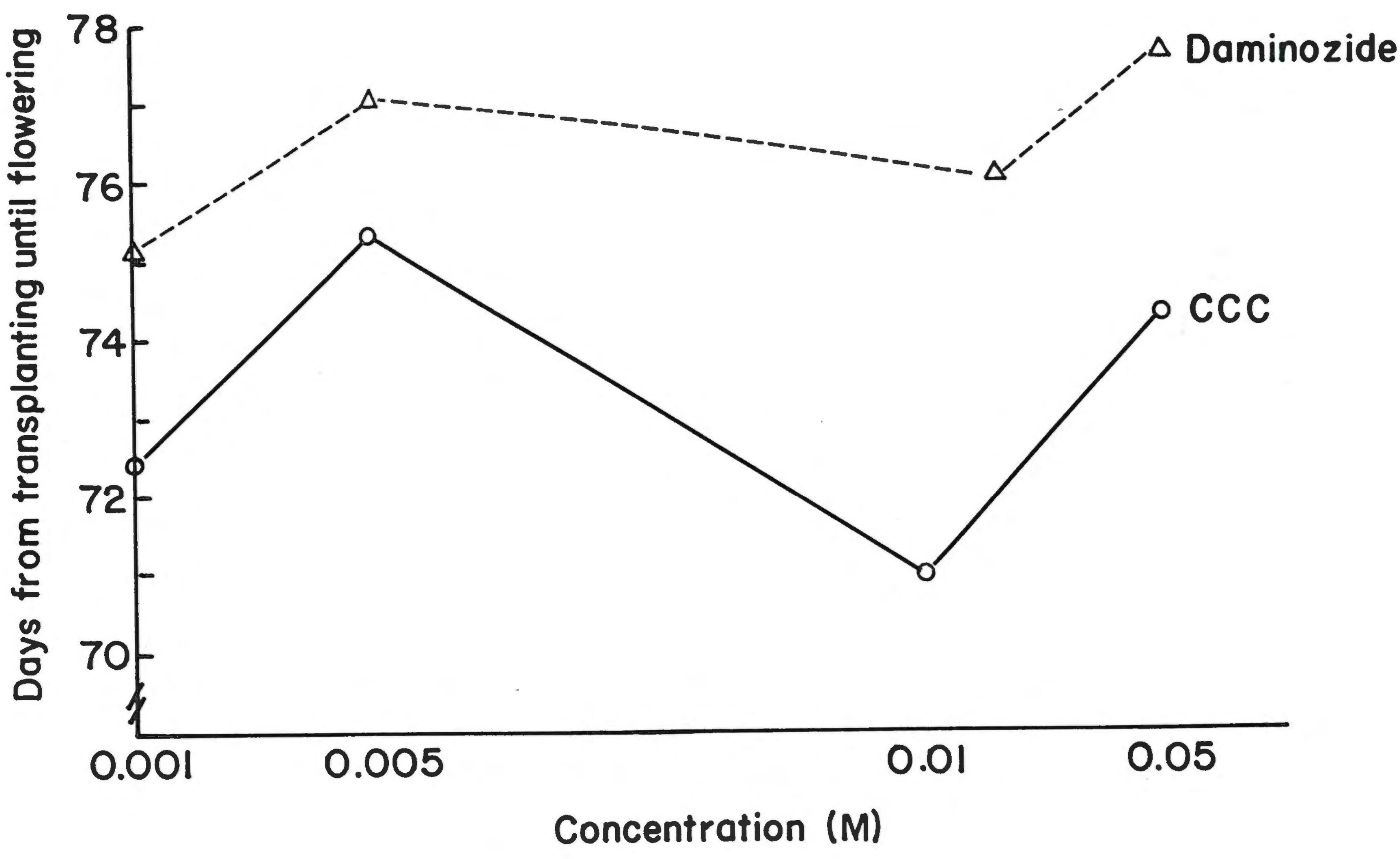


Figure 22. Interactive effect of growth retardant and concentration (semilogarithmic, 2 cycle) on time of flowering of pimiento peppers.

Application of growth retardants accelerated ripening over that of control plants (Figure 23).

During unfavorable environmental conditions, compact plants with large stems and well developed root systems survive better in the field than conventional plants. The greater mass of root development from plant growth regulator treated plants in this study suggests an increase in the capacity for mineral absorption from the soil. Compared to control plants, leaf content of K and Mg were significantly higher due to CCC and Daminozide treatment (Table 5). No differences in N, P, and Ca content were found from growth retardant treatments. On the other hand, CCC treated plants were significantly higher than Daminozide treated plants in P content. Although CCC is a P containing compound, the higher P content of CCC treated plants cannot be attributed to this reason because of the small amount of chemical sprayed onto the plant, at early stage of growth. Similar results were found from all concentrations used (Table 6). Only the content of K and Mg were affected significantly by concentration. There were no significant difference among concentrations but all concentrations were higher than the control in K content. All concentrations increased the content of Mg compared to the control. The highest Mg content was found in the plants receiving the highest concentration (i.e., 5×10^{-2}M). When control plants were compared with treated plants, content of Ca was not affected by concentration but it increased significantly from 3.0 to 3.3 % as the concentration decreased from 5×10^{-2}M to 10^{-3}M. Time of application had no effect on N, P, and Ca content (Table 7). It was

Figure 23. Earlier fruit ripening with the application of growth retardants.

Table 5. Effect of Growth Retardants on Leaf Nutrient Content of Pimiento Peppers in the Greenhouse.

Chemical	Nutrient (%)				
	N	P	K	Ca	Mg
CCC	3.7a[z]	0.50a	6.4a	3.2a	0.70a
Daminozide	3.7a	0.47 b	6.4a	3.3a	0.71a
Control	3.7a	0.49ab	5.7 b	3.2a	0.56 b

[z]Mean separation within columns by Duncan's Multiple Range Test, 5% level.

Table 6. Effect of Concentration of Growth Retardant on Leaf Nutrient Content of Pimiento Peppers in the Greenhouse.

	Nutrient (%)				
Concentration	N	P	K	Ca	Mg
$5x10^{-2}M$	3.6a[z]	0.48a	6.4a	3.0 b	0.73a
$1x10^{-2}M$	3.7a	0.48a	6.4a	3.2ab	0.69ab
$5x10^{-3}M$	3.8a	0.49a	6.4a	3.3a	0.63 b
$1x10^{-3}M$	3.8a	0.47a	6.4a	3.3a	0.71a
Control	3.7a	0.49a	5.7 b	3.2ab	0.56 c

[z]Mean separation within columns by Duncan's Multiple Range Test, 5% level.

Table 7. Effect of Time of Application of Growth Retardants on Leaf Nutrient Content of Pimiento Peppers in the Greenhouse.

Time of Application	Nutrient (%) N	P	K	Ca	Mg
Seed application	3.7a[z]	0.48ab	6.2a	2.9 b	0.62a
2-L stage	3.8a	0.50a	6.3a	3.1ab	0.71a
4-L Stage	3.7a	0.48ab	6.4a	3.2ab	0.69a
Seed + 2-L Stage	3.7a	0.47ab	6.5a	3.3a	0.71a
Seed + 4-L Stage	3.7a	0.47ab	6.5a	3.2ab	0.68a
Seed + 2-L + 4-L Stage	3.7a	0.47ab	6.4a	3.3ab	0.70a
2-L + 4-L Stage	3.7a	0.49ab	6.5a	3.4a	0.71a
Drench	3.8a	0.48ab	6.1a	3.3ab	0.56 b
Control	3.7a	0.49ab	5.7 b	3.2ab	0.56 b

[z]Mean separation within columns by Duncan's Multiple Range Test, 5% level.

found also that the 2-leaf stage was more effective than the seed + 2-leaf + 4-leaf stage in increasing P content. Stages of seed + 2-leaf and 2-leaf + 4-leaf were more effective than seed application in increasing content of Ca. Plant receiving seed application and foliar application as well as the drench application were significantly higher in K content than control plants. Plants treated at different times of application were higher in Mg content than those receiving drench or control plants. The interactive effect of growth retardant, time of application, and season on nutrient content is shown in Table 8. CCC increased K content significantly during the spring compared to Daminozide or control plants when the chemicals were applied at seed + 2-leaf + 4-leaf stage. Growth retardants were effective in increasing P content over that of control when the chemicals were applied at seed + 4-leaf and at 2-leaf + 4-leaf stages in the spring and CCC was more effective than Daminozide in this regard. In the fall, both CCC and Daminozide reduced P content when they were applied at the seed + 2-leaf stage.

The correlation of various plant morphological and physiological features which were significantly influenced by growth retardants with the leaf content of five macro nutrients indicated that uptake of N and P tended to behave oppositely to uptake of K, Mg, and Ca (Table 9). These results are supported by the correlations of the macro nutrients among themselves. Because of a large number of treatments in these experiments, many statistically significant correlations were obtained, however, from the biological standpoint many of these significant

Table 8. Interactive Effect of Growth Retardant, Time of Application, and Season on Leaf Nutrient Content of Pimiento Peppers in the Greenhouse.

	K (%)		p (%)		
	Spring	Fall	Spring		Fall
Chemical	Seed + 2-L + 4-L Stage	Seed + 2-L + 4-L Stage	Seed + 4-L Stage	2-L + 4-L Stage	Seed + 2-L Stage
CCC	6.7a[z]	6.7a	0.56a	0.53a	0.44 b
Daminozide	5.7 b	6.7a	0.49 b	0.51 b	0.39 c
Control	5.7 b	5.7 b	0.49 b	0.49 c	0.49a

[z]Mean separation within columns by Duncan's Multiple Range Test, 5% level.

Table 9. Correlation of Various Plant Morphological and Physiological Features of Pimiento Peppers with the Leaf Content of 5 Macro Nutrients in the Greenhouse.

	Nutrient (%)				
	N	P	K	Mg	Ca
Root length	.004	-.15**	.007	-.09	.09
Stem height	-.42***	0.36**	.17**	.43***	.42***
Days until flowering	.59***	.48**	-.32***	-.72***	-.67***
Top stem diameter	-.62***	-.50***	.35***	.71***	.59***
Base stem diameter	-.51***	-.37***	.14**	.50***	.40***
Yield of first harvest	.06	.16**	-.22***	-.15**	-.30***
Nitrogen		.34***	-.18***	-.57***	-.45***
Phosphorus			-.13**	-.50***	-.56***
Potassium				.29***	.40***
Magnesium					.73***

*Significant at 5% level.

**Significant at 1% level.

***Significant at 0.1% level.

correlations are not important. Some of these which are considered important are discussed. The correlation of top and base stem diameter with the content of these nutrients resulted in a significant negative relationship with content of N and P but in a significant positive one with the content of K, Mg, and Ca. On the other hand, the physiological feature of days until flowering was positively correlated with content of N and P but was negatively correlated with content of K, Mg, and Ca. Shortening the time to flowering and increasing top and base stem diameter resulted in a significant increase in the content of K, Mg, and Ca and decrease in content of N and P. Content of N and P increased concurrently while content of K, Mg, and Ca decreased significantly as N and P increased. With an increase or decrease in the content of any one of the three nutrients; K, Mg, or Ca; there is a corresponding increase or decrease in content of the other two nutrients.

Other correlations were also calculated and it was found that an increase in yield of first harvest resulted when the time to flowering was shortened in the fall. A decrease in stem height resulted in an increase in root length. Shortening the time to flowering also resulted in an increase in both top and base stem diameter ($P<0.01$). A highly significant correlation was also found between top and base stem diameter ($r = 0.74$). In general, several researchers have demonstrated similar responses from growth retardants. An increase in Mg content as a result of treatment with CCC and Daminozide has been reported by Adedipe (3) and by Knavel (33). Similar effects on K content as reported here were also found by Crittendon and Kiplinger (17), but

Adedipe (3), Knavel (33), Ashby and Looney (6), and Himelrick et al. (26) reported a reduction in K content when plants were treated with Alar or CCC. No significant influence of growth retardants on N, P, and Ca was reported by Southwick et al. (66). On the other hand, a reduction in N and P content from Alar treatment was reported by Ashby and Looney (6) and by Himelrick et al. (26). A decrease in Ca with SADH application was demonstrated by Wieneke et al. (79) working with pea and bean plants and by Crittendon and Kiplinger (17) working with Chrysanthemum.

II. Field Experiments

Growth Retardant Experiment

Means were separated by orthogonal contrast test and 28 contrasts out of 30 treatments were made. Each contrast was assigned a number from 1 to 28 as presented in the tables. Only significant contrasts are presented in the tables, and for the convenience of the reader, control means are also presented even though they were not included in the orthogonal comparison.

Treatment with CCC and Daminozide significantly increased the early yield (Table 10 and 11). Normally, pimiento pepper fruits ripen about 90 days after transplanting. In the present investigation fruits from treated plants started to ripen about 12-15 days earlier than normal. The first harvest was on the 82 day after transplanting. In different times of application, (i.e., seed + 2-leaf, seed + 4-leaf, 2-leaf + 4-leaf, and seed + 2-leaf + 4-leaf stages), 10^{-2}M CCC was more

Table 10. Effect of CCC and Daminozide on Number of Ripe Pimiento Pepper Fruits at the First Harvest.

Contrast Number	Comparison	Time of application or Chemical Uses	Means*
1	10^{-2}M CCC vs. 5x10^{-2}M Daminozide	S + 2L, S + 4L, 2L + 4L, S + 21 + 4L	6.3a[z] vs. 2.6 b
10	Seed application vs. (2L, 4L)	10^{-2}M CCC and 5x10^{-2}M Daminozide	2.9 b vs. 7.4a
11	(CCC-2L and Daminozide-4L) vs. (Daminozide-2L and CCC-4L)	10^{-2}M CCC and 5x10^{-2}M Daminozide	3.9 b vs. 11.0a
12	(CCC-S and Daminozide-2L and 4L) vs. (Daminozide-S and CCC-2L and 4L)	10^{-2}M CCC and 5x10^{-2}M Daminozide	3.5 b vs. 8.4a
15	Seed application vs (2L, 4L)	10^{-2}M CCC and 10^{-2}M Daminozide	4.3 b vs. 8.4a
16	(CCC-2L and Daminozide-4L) vs. (Daminozide-2L and CCC-4L)	10^{-2}M CCC and 10^{-2}M Daminozide	5.7 b vs. 11.1a
17	(CCC-S and Daminozide-2L and 4L) vs. (Daminozide-S and CCC-2L & 4L)	10^{-2}M CCC and 10^{-2}M Daminozide	4.7 b vs. 9.3a
26	(10^{-2}M-2L and 10^{-3}M-4L) vs. (10^{-3}M-2L and 10^{-2}M-4L)	Daminozide	11.5a vs. 6.6 b
--	Control	----	3.6

*The first mean refers to the treatment(s) in the first grouping of the respective contrast.

[z]Differences tested with preplanned contrast. All contrasts are orthogonal.

Table 11. Effect of CCC and Daminozide on Early Yield of Pimiento Pepper.

Contrast Number	Comparison	Time of application or Chemical Uses	Means* (MT/ha)
1	10^{-2}M CCC vs. 5x10^{-2}M Daminozide	S + 2L, S + 4L, 2L + 4L, S + 2L + 4L	0.9a[z] vs. 0.4 b
10	Seed application vs. (2L, 4L)	10^{-2}M CCC and 5x10^{-2}M Daminozide	0.4 b vs. 0.9a
11	(CCC-2L and Daminozide-4L) vs. (Daminozide-2L and CCC-4L)	10^{-2}M CCC and 5x10^{-2}M Daminozide	0.4 b vs. 1.3a
16	(CCC-2L and Daminozide-4L) vs. (Daminozide-2L and CCC-4L)	10^{-2}M CCC and 10^{-2}M Daminozide	0.6 b vs. 1.3a
17	(CCC-S and Daminozide-2L and 4L) vs. (Daminozide-S and CCC-2L and 4L)	10^{-2}M CCC and 10^{-2}M Daminozide	0.6 b vs. 1.0a
19	2L vs. 4L	5x10^{-2}M Daminozide and 5x10^{-3}M Daminozide	1.3a vs. 0.6 b
26	(10^{-2}M-2L and 10^{-3}M-4L) vs. (10^{-3}M-2L and 10^{-2}M-4L)	Daminozide	1.5a vs. 0.9 b
27	(10^{-2}M-S and 10^{-3}M-2L and 4L) vs. (10^{-3}M-S and 10^{-2}M-2L and 4L)	Daminozide	1.4a vs. 0.8 b
--	Control	----	0.6

*The first mean refers to the treatment(s) in the first grouping of the respective contrast.

[z]Differences tested with preplanned contrasts. All contrasts are orthogonal.

effective than $5x10^{-2}M$ Daminozide (Contrast 1). The foliar application (2-leaf and 4-leaf stages) of CCC and Daminozide resulted in a significantly higher number and yield of red ripe fruits than the seed application (Contrast 10 and 15). In addition the 2-leaf stage resulted in a significantly higher early yield than 4-leaf stage when Daminozide was applied at different concentrations, $5x10^{-2}$ and $5x10^{-3}M$ (Contrast 19). An interaction effect of chemical and time of application was also obtained. Using a high chemical concentration ($10^{-2}M$), CCC as a foliar application (2-leaf and 4-leaf stages) resulted in a higher number of fruits and yielded more than Daminozide, while the reverse result was obtained at seed application (Contrast 17). On the other hand, Daminozide was more effective than CCC at the 2-leaf stage, but at the 4-leaf stage CCC was the most effective one (Contrast 11 and 16). A high concentration was used in both comparisons. A significant interaction effect between the concentration and time of application was also obtained with Daminozide. Early yield was significantly higher in plants receiving $10^{-2}M$ than those receiving $10^{-3}M$ concentration when the chemicals were applied to the seed, while the lower concentration of $10^{-3}M$ was more effective than $10^{-2}M$ when the chemicals were applied foliarly at the 2-leaf and 4-leaf stages (Contrast 27). Similar results were found with the interaction of these concentrations with 2-leaf and 4-leaf stages (Contrast 26). The higher concentration was more effective at the early stage, 2-leaf, while the reverse was true at 4-leaf stage. In comparing the higher mean in each of these contrasts with the control, it can be seen that the control plant had a lower number of ripe fruits and, subsequently a lower early yield. Read (49) found similar results when CCC and Alar were applied on tomato plants as a foliar spray. He reported an increase of early and total yield. Similar results were also demonstrated by Knavel (33) on tomato plants treated with Alar at the 3-leaf stage. He found an increase in number and weight of early fruit in plants treated with Alar at 2500 ppm.

Number and weight of green fruits at the fourth harvest are shown in Tables 12 and 13, respectively. Daminozide at $5x10^{-2}M$ significantly reduced both the number and the weight of green fruits in comparison with CCC at $10^{-2}M$ when they were applied at different times (Contrast 1 and 8). The foliar application at 2-leaf and 4-leaf stages reduced significantly both number and weight of green fruits compared with the seed application when CCC and Daminozide were used at the concentration of 10^{-2} and $5x10^{-2}M$, respectively (Contrast 10). CCC applied at $10^{-3}M$ at 2-leaf stage resulted in a lower fruit weight than when applied as a drench (Contrast 28). On the other hand, 4-leaf stage was more effective than 2-leaf stage in reducing weight of green fruits. An interaction effect between the chemicals and stage of application was found when the $10^{-2}M$ concentration was used. CCC applied at 2-leaf stage reduced the number and the weight of green fruits more than Daminozide, but Daminozide was more effective than CCC at 4-leaf stage (Contrast 16).

The number and the yield of red ripe fruits at the fourth harvest are shown in Tables 14 and 15. A high concentration of CCC and Daminozide

Table 12. Effect of CCC and Daminozide on Number of Green Pimiento Pepper Fruits at the Fourth Harvest.

Contrast Number	Comparison	Time of application or Chemical Uses	Means* (No/Plot)
1	10^{-2}M CCC vs. 5×10^{-2}M Daminozide	S + 2L, S + 4L, 2L + 4L, S + 2L + 4L	69.1a[z] vs. 53.4 b
5	(CCC-S+2L and S+4L and Daminozide-2L+4L) vs. (Daminozide-S+2L and 4L and CCC-2L+4L)	10^{-2}M CCC and 5×10^{-2}M Daminozide	52.4 b vs. 67.4a
8	10^{-2}M CCC vs. 5×10^{-2}M Daminozide	S, 2L, and 4L	77.3a vs. 61.8 b
10	Seed application vs. (2L, 4L)	10^{-2}M CCC and 5×10^{-2}M Daminozide	83.2a vs. 63.0 b
16	(CCC-2L and Daminozide-4L) vs. (Daminozide-2L and CCC-4L)	10^{-2}M CCC and 10^{-2}M Daminozide	63.9 b vs. 76.4a
22	(5×10^{-2}M-S and 5×10^{-3}M-2L and 4L) vs. (5×10^{-3}-S and 5×10^{-2}M-2L and 4L)	Daminozide	61.7a vs. 49.9 b
24	2L vs 4L	10^{-2}M Daminozide and 10^{-3}M Daminozide	84.9a vs. 60.5 b
--	Control	----	61.4

*The first mean refers to the treatment(s) in the first grouping of the respective contrast.

[z]Differences tested with preplanned contrasts. All contrasts are orthogonal.

Table 13. Effect of CCC and Daminozide on Weight of Green Pimiento Pepper Fruits at the Fourth Harvest.

Contrast Number	Comparison	Time of application or Chemical Uses	Means* (MT/ha)
1	10^{-2}M CCC vs. 5x10^{-2}M Daminozide	S + 2L, S + 4L, 2L + 4L, S + 2L + 4L	5.2a^{z} vs. 3.9 b
8	10^{-2}M CCC vs. 5x10^{-2}M Daminozide	S, 2L, 4L	5.9a vs. 4.2 b
10	Seed application vs. (2L, 4L)	10^{-2}M CCC and 5x10^{-2}M Daminozide	6.0a vs. 4.6 b
16	(CCC-2L and Daminozide-4L) vs. (Daminozide-2L and CCC-4L)	10^{-2}M CCC and 10^{-2}M Daminozide	4.8 b vs. 6.5a
24	2L vs. 4L	10^{-2}M Daminozide and 10^{-3}M Daminozide	6.1a vs. 4.4 b
28	Foliar spray vs. Drench	10^{-3}M CCC - 2L	4.6 b vs. 6.9a
--	Control	----	4.7

*The first mean refers to the treatment(s) in the first grouping of the respective contrast.

^{z}Differences tested with preplanned contrast. All contrasts are orthogonal.

Table 14. Effect of CCC and Daminozide on Number of Ripe Pimiento Pepper Fruits at the Fourth Harvest.

Contrast Number	Comparison	Time of application or Chemical Uses	Means* (No/Plot)
10	Seed application vs. (2L, 4L)	10^{-2}M CCC and $5x10^{-2}$M Daminozide	16.0a[z] vs. 9.5 b
11	(CCC-2L and Daminozide-4L) vs. (Daminozide-2L and CCC-4L)	10^{-2}M CCC and $5x10^{-2}$M Daminozide	12.6a vs. 6.3 b
15	Seed application vs. (2L, 4L)	10^{-2}M CCC and 10^{-2}M Daminozide	14.0a vs. 6.8 b
19	2L vs. 4L	$5x10^{-2}$M Daminozide and $5x10^{-3}$M Daminozide	6.7 b vs. 13.0a
20	Foliar spray vs. Drench	10^{-3}M CCC-2L	12.5a vs. 10.0 b
--	Control	----	10.1

*The first mean refers to the treatment(s) in the first grouping of the respective contrast.

[z]Differences tested with preplanned contrasts. All contrasts are orthogonal.

Table 15. Effect of CCC and Daminozide on Yield of Ripe Pimiento Pepper Fruits at the Fourth Harvest.

Contrast Number	Comparison	Time of application or Chemical Uses	Means* (MT/ha)
10	Seed application vs. (2L, 4L)	10^{-2}M CCC and $5x10^{-2}$M Daminozide	1.8a^{z} vs. 1.0 b
11	(CCC-2L and Daminozide-4L) vs. (Daminozide-2L and CCC-4L)	10^{-2}M CCC and $5x10^{-2}$M Daminozide	1.4a vs. 0.7 b
15	Seed application vs. (2L, 4L)	10^{-2}M CCC and 10^{-2}M Daminozide	1.5a vs. 0.7 b
19	2L vs. 4L	$5x10^{-2}$M Daminozide and $5x10^{-3}$ Daminozide	0.7 b vs. 1.5a
--	Control	----	1.1

*The first mean refers to the treatment(s) in the first grouping of the respective contrast.

^{z}Differences tested with preplanned contrasts. All contrasts are orthogonal.

as a seed application produced a significantly higher number and yield of red ripe fruit than foliar application at 2-leaf and 4-leaf stages (Contrast 10 and 15). The seed treatment appeared to delay fruit ripening since this treatment always resulted in lower early yields than foliar treatments (Tables 10 and 11, pp. 74 and 75, Contrast 10). On the other hand, plants receiving application at 4-leaf stage produced more red ripe fruits than those receiving application at 2-leaf stage when Daminozide was applied at concentrations of $5x10^{-2}M$ and $5x10^{-3}M$ (Contrast 19). CCC at $10^{-3}M$ applied at 2-leaf stage as foliar spray resulted in a higher number of fruits than when applied as a drench (Contrast 28). An interaction between chemical and time of application also resulted in a significant effect. CCC at $10^{-2}M$ applied at 2-leaf stage and Daminozide at $5x10^{-2}M$ applied at 4-leaf stage resulted in a higher number of fruits and a higher yield than CCC and Daminozide applied at 4-leaf and 2-leaf stages, respectively. When comparing the higher mean in each of these contrasts discussed here with the mean of the control, it can be seen that the control plant had a lower number of fruits and yield.

The effect of growth retardants, CCC and Daminozide, on marketable yield is presented in Table 16. Foliar applications of Daminozide at concentrations of $5x10^{-2}M$ and $5x10^{-3}M$ at the 2-leaf and 4-leaf stages produced higher marketable yields than seed application (Contrast 20). Daminozide applied at concentrations of $5x10^{-2}M$ and $5x10^{-3}M$ and with CCC and Daminozide applied at concentrations of $10^{-2}M$ and $5x10^{-2}M$, respectively, the 4-leaf stage resulted in a higher marketable yield than the 2-leaf stage (Contrast 9 and 19).

Table 16. Effect of CCC and Daminozide on Marketable Yield of Pimiento Peppers.

Contrast Number	Comparison	Time of application or Chemical Uses	Means* (MT/ha)
9	2L vs. 4L	10^{-2}M CCC and $5x10^{-2}$M Daminozide	5.6 b^{z} vs. 9.1a
19	2L vs. 4L	$5x10^{-2}$M Daminozide and $5x10^{-3}$M Daminozide	5.3 b vs. 10.7a
20	Seed application vs. (2L, 4L)	$5x10^{-2}$M Daminozide and $5x10^{-3}$M Daminozide	5.4 b vs. 8.0a
--	Control	----	8.3

*The first mean refers to the treatment(s) in the first grouping of the respective contrast.

^{z}Differences tested with preplanned contrasts. All contrasts are orthogonal.

Total yield was significantly higher at the 4-leaf stage than at the 2-leaf stage of application when Daminozide at concentrations of $5x10^{-2}$ and $5x10^{-3}M$ was used (Table 17, Contrast 19). The same results were also found when CCC at a concentration of $10^{-2}M$ and Daminozide at a concentration of $5x10^{-2}M$ were used (Contrast 9). The yields from these treatments were significantly higher than control plants.

Daminozide at $5x10^{-2}M$ was more effective in increasing total yield than at $5x10^{-3}M$ when the chemical was applied to the seed while the reverse was true when the chemical was applied foliarly at the 2-leaf and 4-leaf stages. Similar yield responses of pimiento pepper from CCC and SADH were found by Joshi (31). Tiessen (70) also reported an increase of tomato and pepper yield when CCC was applied at the seedling stage. Yield increases of tomatoes from foliar sprays of CCC and Alar have also been reported (49).

The effect of growth retardants, CCC and Daminozide, on the average weight of ripe fruits is shown in Table 18. Average fruit weight is one of the important grading criteria for pimiento pepper. A minimum fruit diameter of 4 cm (about 50 gm in weight) is acceptable for the processing market. Application of the two chemicals at the higher concentrations at the seed + 4-leaf stage resulted in a higher average weight of ripe fruit than the seed + 2-leaf stage (Contrast 3). On the other hand, Daminozide at $10^{-2}M$ at 2-leaf stage was more effective than at $10^{-3}M$ in increasing average weight of ripe fruit while the reverse was true at 4-leaf stage (Contrast 26). An interaction effect was also present between the time of application and chemical used.

Table 17. Effect of CCC and Daminozide on the Total Yield of Pimiento Peppers.

Contrast Number	Comparison	Time of application or Chemical Uses	Means* (MT/ha)
9	2L vs. 4L	10^{-2}M CCC and 5x10^{-2}M Daminozide	11.0 b^{z} vs. 15.1a
19	2L vs. 4L	5x10^{-2} Daminozide and 5x10^{-3}M Daminozide	10.4 b vs. 15.8a
22	(5x10^{-2}M-S and 5x10^{-3}-2L and 4L) vs. (5x10^{-3}M-S and 5x10^{-2}M-2L and 4L)	Daminozide	13.2a vs. 11.2 b
--	Control	----	14.1

*The first mean refers to the treatment(s) in the first grouping of the respective contrast.

^{z}Differences tested with preplanned contrasts. All contrasts are orthogonal.

Table 18. Effect of CCC and Daminozide on Average Weight of Ripe Pimiento Pepper Fruits.

Contrast Number	Comparison	Time of application or Chemical Uses	Means* g
3	S + 2L vs. S + 4L	10^{-2}M CCC and 10^{-2}M Daminozide	54.4 b[z] vs. 59.0a
7	(CCC-S + 2L, S + 4L and 2L + 4L, and Daminozide-S + 2L + 4L) vs. (Daminozide-S + 2L, S + 4L and 2L + 4L, and CCC-S + 2L + 4L)	10^{-2}M CCC and $5x10^{-2}$M Daminozide	54.4 b vs. 59.0a
26	(10^{-2}M-2L and 10^{-3}M-4L) vs. (10^{-3}M-2L and 10^{-2}M-4L)	Daminozide	59.0a vs. 54.4 b
--	Control	----	54.4

*The first mean refers to the treatment(s) in the first grouping of the respective contrast.

[z]Differences tested with preplanned contrasts. All contrasts are orthogonal.

CCC at 10^{-2}M was more effective than Daminozide at $5x10^{-2}$M when the chemicals were applied two times while the reverse was true when the chemicals were applied three times (Contrast 7).

Topping Experiment

The effect of topping and plant size on early yield is shown in Table 19. Plants topped once or twice increased significantly both the total number and weight of red ripe fruits while transplant size had no effect on these characters. This resulted from limiting the growth by topping at time of transplanting (Figure 24). Topping resulted in a cessation of apical growth which could have made more photosynthate and nutrients available for reproductive growth. Similar results were found by Dempsey (18) who reported that oversized pimiento transplants topped to 12 or 16 inches in height produced higher yields of marketable red ripe fruits than transplants not topped or topped 8 inches in height. Jaworski and Webb (28) found an increase in yields of pepper when plants were clipped 12 days prior to transplanting.

Topped plants produced fewer green fruits than untopped of various sizes but topping or transplant size had no effect on weight of green fruits (Table 20). Plants topped three times reduced significantly the weight of green fruits compared to small size or control plants.

From the data presented in Table 21, it can be seen there were no significant effects from topping or plant size on marketable yield, except that small sized plants and plants topped three times yielded less than larger plants and plants topped fewer times.

Table 19. Effect of Mechanical Topping and Plant Size on Early Yield of Pimiento Peppers.

Treatment Number	Treatments	Total Number Ripe fruits per plot	Weight of Ripe fruits (MT/ha)
1	Mixed size plant	1.8 cd[z]	0.4 c
2	Large size plant	1.5 cd	0.3 c
3	Medium size plant	3.3 cd	0.7abc
4	Small size plant	1.3 d	0.3 c
5	Plant topped once	8.0a	1.2a
6	Plant topped twice	7.0ab	1.1ab
7	Plant topped three times	4.8abc	0.7abc
8	Plant not topped (control)	3.8 bcd	0.5 c

[z]Means separated by Duncan's Multiple Range Test, 5% level.

Figure 24. Topped plants used in the field experiments.

Table 20. Effect of Mechanical Topping and Plant Size on Yield of Green Pimiento Pepper Fruits.

Treatment Number	Treatments	Total Number per plot	Weight of Green Fruits (MT/ha)
1	Mixed size plant	10.4ab^{z}	0.7 b
2	Large size plant	13.5a	1.3ab
3	Medium size plant	11.9a	1.6ab
4	Small size plant	12.0a	2.0a
5	Plant topped once	6.4 c	1.2ab
6	Plant topped twice	6.5 c	1.4ab
7	Plant topped three times	7.4 bc	0.9 b
8	Plant not topped (control)	8.0 bc	2.0a

^{z}Means separated by Duncan's Multiple Range Test, 5% level.

Table 21. Effect of Mechanical Topping and Plant Size on Marketable Yield of Pimiento Peppers.

Treatment Number	Treatment	Marketable Yield (MT/ha)
1	Mixed size plant	6.0ab
2	Large size plant	5.8ab
3	Medium size plant	6.0ab
4	Small size plant	5.4 b
5	Plant topped once	7.0ab
6	Plant topped twice	7.2ab
7	Plant topped three times	4.9 b
8	Plant not topped (control)	8.3a

[z]Means separated by Duncan's Multiple Range Test, 5% level.

CHAPTER V

SUMMARY AND CONCLUSIONS

This study consisted of both greenhouse and field experiments. The effect of growth retardants (Daminozide and CCC), concentrations, and times of application on pimiento pepper seedlings were studied to determine at what physiological stage the retardants are most effective in altering the morphological characteristics of size and shape and physiological characteristics of flowering, fruit development, ripening, and subsequent marketable yield of pimiento plants.

One of the first differences observed relative to the effect of these retardants on the pimiento plants was an enhancement of green color of pimiento foliage. Treated plants had thicker, more succulent leaves than untreated plants. Treated plants were also shorter, stockier, and had more extensive root systems than untreated plants. Both chemicals increased the root length over that of the control plants. Plants receiving repeated applications of 10^{-3}M retardants at seed + 2-leaf + 4-leaf stage had a larger mass of roots. Both growth retardants reduced stem height and Daminozide was more effective in this regard. Stem height was reduced by all concentrations, the $5x10^{-2}$ reducing it the most and the $1x10^{-3}$M reducing it the least. Multiple applications of growth retardants at 2-leaf + 4-leaf or at seed + 2-leaf + 4-leaf stages were the most effective treatments in limiting stem height. The major retardant effects of Daminozide and CCC were noticed in the subapical region where internodal elongation was retarded without having any apparent phytotoxic effect on further growth of pimiento seedlings.

Daminozide and CCC increased top stem diameter over that of controls. CCC was more effective than Daminozide in this response. The concentration of $5x10^{-2}M$ was the most effective rate on stem diameter. The repeated applications, seed + 4-leaf and 2-leaf + 4-leaf stages, were the only stages that resulted in an increase in stem diameter. The greatest stem diameter was observed with CCC at seed application in the fall.

Control of vegetative growth by the application of growth retardants, mainly during the early stages of plant growth, had a significant influence on the subsequent development of early flowering of pimiento. CCC enhanced flowering more than Daminozide. In the fall, CCC and Daminozide treated plants bloomed from 6-17 days earlier than control plants at most of the stages of application.

From the greenhouse experiments, it seems that plants grown in the fall responded more to growth retardants than those grown in the spring. Treated plants grown in the fall had more extensive root systems, greater height reduction, thicker stems, flowered earlier, and yielded more than those grown in the spring. The environmental conditions, especially temperature, were more favorable to pimiento in the fall which might have resulted in a synergetic effect with the growth retardants.

In the greenhouse study, both CCC and Daminozide accelerated ripening over that of control plants but they had no effect on yield. CCC was more effective in this regard.

Compared to control plants, the leaf content of K and Mg was significantly increased from all concentrations and stages of applications of growth retardants but N, P, and Ca were not influenced. When comparing CCC treated plants with Daminozide treated plants, CCC treated plants were higher in P content. Certain plant morphological features influenced by growth retardants showed positive and some negative correlations with the plant contents of N and P and negative and some positive correlations with plant contents of K, Mg, and Ca.

Application of CCC and Daminozide resulted in earlier fruit ripening and significantly increased the early yield in the field. Fruits from treated plants started to ripen about 12-15 days earlier than normal.

At different times of application, 10^{-2}M CCC was more effective in increasing early yield than $5x10^{-2}$M Daminozide. Foliar application of these growth retardants at the early stage resulted in a higher early and marketable yield than other times of application. Application of growth retardants at 4-leaf stage resulted in marketable yield about two times that of application at 2-leaf stage. Total yield was also higher at the 4-leaf stage. Daminozide and CCC were also effective in increasing the average weight of ripe fruit over that of control plants. From these results it appears that yield of pimiento pepper can be increased from the application of growth retardants.

Plants topped once or twice increased both the total number and weight of red ripe fruits while transplant size had no effect on these characters. This resulted from limiting the plant growth by topping at time of transplanting. Topping had no effect on marketable yields.

By application of growth retardants, it may be possible to produce transplants with thicker leaves and stems and shorter internodes which would flower earlier than normal, and therefore would be useful in the production of plants for mechanical transplanting. Results of this research suggest that application of growth retardants at the seedling stage to pimiento plants will help prevent the problem of oversized transplants which often develops during an unfavorable season. Similar benefits can be obtained with mechanical topping. So, in this regard it is possible that plant growth retardants may substitute for mechanical topping. During unfavorable environmental conditions, compact plants with large stems and well developed root systems survive better in the field than conventional plants. From these investigations it appears that CCC was more effective than Daminozide in most of the characteristics studied. It appears that application of CCC at the 10^{-2}M at 2-leaf stage may enhance ripening and thus facilitate earlier harvesting.

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APPENDIX

Table 22. Combined Analyses of Variance of Certain Morphological and Physiological Characteristics of Pimiento Pepper in the Greenhouse, Spring and Fall, 1979.

Source	D.F.	Root Length	Stem Height	Days From Transplanting Until Flowering	Top Stem Diameter
Season (S)	1	N.S.	**	**	**
Replication Within Season	4				
Chemical (B)	1	N.S.	**	**	N.S.
Concentration (C)	3	**	**	**	**
Stage (D)	6	**	**	N.S.	*
BXC	3	**	*	N.S.	*
BXD	6	N.S.	**	N.S.	N.S.
BXS	1	N.S.	N.S.	**	**
CXD	18	**	**	N.S.	N.S.
CXS	3	**	**	N.S.	*
DXS	6	**	**	N.S.	N.S.
BXCXD	18	**	**	N.S.	N.S.
BXCXS	3	**	N.S.	N.S.	N.S.
BXDXS	6	**	N.S.	**	N.S.
CXDXS	18	**	**	N.S.	*
BXCXDXS	18	**	*	N.S.	N.S.

*Significant at 5% level.
**Significant at 1% level.
N.S.—Not Significant

Table 23. Combined Analyses of Variance of Yield of Pimiento Pepper in the Greenhouse, Spring and Fall 1979.

Source	D.F.	Yield Early	Yield Marketable	Yield Total
Season (S)	1	**	N.S.	**
Replication Within Season	4			
Chemical (B)	1	N.S.	**	**
Concentration (C)	3	N.S.	*	N.S.
Stage (D)	6	N.S.	N.S.	N.S.
BXC	3	**	**	**
BXD	6	N.S.	N.S.	N.S.
BXS	1	**	**	**
CXD	18	N.S.	N.S.	N.S.
CXS	3	N.S.	**	*
DXS	6	N.S.	N.S.	N.S.
BXCXD	18	N.S.	N.S.	N.S.
BXCXS	3	N.S.	*	N.S.
BXDXS	6	N.S.	N.S.	N.S.
CXDXS	18	N.S.	**	*
BXCXDXS	18	N.S.	*	N.S.

*Significant at 5% level.
**Significant at 1% level.
N.S.—Not Significant

Table 24. Combined Analyses of Variance of Leaf Macro Nutrient Contents of Pimiento Pepper in the Greenhouse, Spring and Fall 1979.

Source	D.F.	Nutrient (%) N	P	K	Ca	Mg
Season (S)	1	**	**	**	**	**
Replication Within Season	4					
Chemical (B)	1	N.S.	**	N.S.	N.S.	N.S.
Concentration (C)	3	N.S.	N.S.	N.S.	**	**
Stage (D)	6	N.S.	N.S.	N.S.	*	N.S.
BXC	3	*	N.S.	N.S.	N.S.	*
BXD	6	N.S.	N.S.	N.S.	N.S.	N.S.
BXS	1	*	N.S.	N.S.	N.S.	N.S.
CXD	18	N.S.	**	N.S.	N.S.	N.S.
CXS	3	*	N.S.	N.S.	N.S.	**
DXS	6	N.S.	N.S.	N.S.	N.S.	N.S.
BXCXD	18	N.S.	N.S.	N.S.	N.S.	N.S.
BXCXS	3	N.S.	N.S.	N.S.	N.S.	N.S.
BXDXS	6	N.S.	**	N.S.	N.S.	N.S.
CXDXS	18	N.S.	N.S.	N.S.	N.S.	N.S.
BXCXDXS	18	N.S.	N.S.	N.S.	N.S.	*

*Significant at 5% level.
**Significant at 1% level.
N.S.—Not Significant.

VITA

Fadhil M. Humadi was born in Fallujah, Iraq, on October 26, 1945. He was educated in the elementary and secondary schools of that city and was graduated from Al-Fallujah High School in June 1962. The following September he entered the College of Agriculture, University of Baghdad, receiving a Bachelor's degree in Agriculture in June 1966. The following October he was employed as a teacher by the Iraqi Ministry of Education in the Al-Ramadi Vocational Agricultural High School. In September 1969, he was employed as a demonstrator by the University of Riyadh, Saudi Arabia, in the College of Agriculture as part of the Educational Assistance Program between the governments of Iraq and Saudi Arabia. In September 1974, he was employed as a demonstrator by the Iraqi Ministry of High Education and Scientific Research in the College of Agriculture, University of Baghdad and at the same time he was awarded a leave of absence from the same university to study toward a Master of Science degree in Horticulture Science. In December 1976, he was granted a Master of Science degree and worked as an assistant teacher in the Department of Horticulture, University of Baghdad until December 1977, when he was awarded a scholarship from the Iraqi Ministry of High Education and Scientific Research to study toward the Ph.D. degree in Horticulture Science. He entered The University of Tennessee Graduate School, on January 5, 1978. In December 1980, he was granted a Ph.D. degree with a major in Plant and Soil Science. He is a member of Gamma Sigma Delta, the Honor Society in Agriculture, Phi Kappa Phi, and the American Society for Horticultural Science.

He was married to Bahija H. Al-Abdeli on December 7, 1970. He is the father of four children, one son, Nabil and three daughters, May, Benan, and Loubna.